EARLY TERTIARY *CYCLAMMINA* AND *HAPLOPHRAGMOIDES* (FORAMINIFERIDA:LITUOLIDAE) IN SOUTHERN AUSTRALIA

by N. H. LUDBROOK

Summary

LUDBROOK, N. H. (1977)—Early Tertiary *Cyclammina* and *Haplophragmoides* (Foraminiferida: Lituolidae) in southern Australia. *Trans. R. Soc. S. Aust.* **101**(7), 165-197, 30 November, 1977.

The genus *Cyclammina* is represented in southern Australian Tertiary deposits by five species whose internal and external morphologies are described: *C. complanata* Chapman, *C. otwayensis* n.sp. and *C. paupera* Chapman, which are restricted to sediments of Palaeocene to Middle Eocene age, and *C. incisa* (Stache) and *C. rotundata* Chapman & Crespin, which usually occur together over a wide geographical range and have a long stratigraphic range from Palaeocene to Early Miocene. Their palaeogeographical and palaeoecological significance and their stratigraphic utility are discussed.

A species of *Haplophragmoides* occurring in Late Cretaceous assemblages and with *Cyclammina* in the Palaeocene is described as *Haplophragmoides taylori* n.sp.

Introduction

Since it was first recognised by Chapman (1904) in ochreous brown clay from Brown's Creek in Victoria, the genus *Cyclammina* has occupied a prominent place in the literature on early Tertiary sediments of southern Australia. It occurs abundantly and in some parts of the sequence, particularly in the Gambier Embayment of the Otway Basin and in the Torquay Basin, is the dominant and, apart from marine dinoflagellates, almost the only marine microfossil occurring in Palaeocene and Eocene paralic silts and sands. In the past, its stratigraphic potential was discounted and only superficial attention was paid to its internal structure. Knowledge of the internal structure of *Cyclammina* species has been greatly advanced by the work of Bronnimann (1951), Voloshinova & Budasheva (1961), Serova (1964) and Banner (1966, 1970).

The present paper is designed to vindicate the early work of Chapman in correctly recognising the genus *Cyclammina*, separable into several species, and to support the conclusions of Taylor (1965) that the species in the Otway Basin have stratigraphic value. Glaessner's view (1951) that *Cyclammina* was not a reliable index fossil appears to have prompted Baker (1953) and Harris (1965) to discount its stratigraphic potential. Taylor's contention that arenaceous forms previously assigned to *Cyclammina* are, in fact, *Haplophragmoides*, is shown to be based on a misunderstanding of the internal morphology of the species and to have been influenced by bathymetric and ecological interpretations.

Five species of *Cyclammina* are recognised. *C. complanata* Chapman, *C. incisa* (Stache), *C. otwayensis* n.sp., *C. paupera* Chapman and *C. rotundata* Chapman & Crespin. A species described by Taylor as *Haplophragmoides* sp. B was correctly placed in *Haplophragmoides*. It occurs in the Late Cretaceous with a small benthonic assemblage and in Palaeocene assemblages with *Cyclammina*, and is here named and described as *Haplophragmoides taylori* n.sp.

Abbreviations used are as follows:

S.A.D.M.	Department of Mines, South Australia
E.&W.S.	Engineering and Water Supply Department, South Australia
V.M.D.	Mines Department, Victoria
B.P.N.L.	Beach Petroleum No Liability
O.D.N.L.	Oil Development No Liability
P.A.C.	Point Addis Company
S.E.O.S.	South East Oil Syndicate
CPC	Commonwealth Palaeontological Collection, Canberra
GSSA	Geological Survey of South Australia Collection

GSM	Geological Survey of Victoria Collection
NMV	National Museum of Victoria Collection
WAM	Western Australian Museum Collection
NZGS	Geological Survey of New Zealand Collection

Historical records of *Cyclammina* in southern Australia

Chapman (1904) recorded *Haplophragmium latidorsatum* (Bornemann), *H. glomeratum* Brady and *H. canariense* (d'Orbigny)—and described *Cyclammina complanata* and *C. paupera*—from Brown's Creek. His sample was collected by Kitson from a locality between Rotten Point and the mouth of the Johanna River 13.6 km northwest of Cape Otway, Port Campbell Embayment of the Otway Basin, in the lower 1.3 m of the Johanna River Sands (see map and section, Carter 1958, p. 8). In the section exposed between Rotten Point and Brown's Creek described as Section 28 by Raggatt and Crespin (1955, p. 134), the lowest 25.6 m (84 feet) comprise the Rotten Point Sands, and the overlying 24.4 m (80 feet) the Johanna River Sands (Carter 1958, p. 10) from the 0.6 m (2 feet) bed of "grey to purplish-brown shale with *Cyclammina*" of which Chapman's material is presumed to have been collected (Carter 1958, p. 10; Taylor 1965, p. 151).

Taylor (1965, p. 157) considered that the presence of *C. complanata* and *C. paupera* gave evidence of a Palaeocene age for the lower part of the Johanna River Sands, and, while this is possible, there is no firm supporting evidence, and the age could be somewhat younger. Some support for an age younger than Palaeocene is given by Harris's (1971, p. 83) recognition of his *Proteacidites pachypolus* Zonule (Middle Eocene, P10 to P13 of Blow, 1969) (McGowran *et al.* 1971, Enclosure 14.1) in dark purple to black carbonaceous silts, sands and clays he referred to the Johanna River Sands, without identifying the sediments with those described by Carter (1958). Harris reported that derived Palaeocene species were also present. However, preservation of the *Cyclammina* spp. described by Chapman (1904) is such that it is unlikely that they were derived from older sediments.

Chapman's figured specimens (1904, pl. 22) are, with one exception, mounted on NMV Slide P26049; they are clearly identifiable from Chapman's figures. The specimen figured as *Haplophragmium canariense* (d'Orbigny) (pl. 22, fig. 2) is however, not on the slide; the specimen on square 2 is not *"H. canariense"*, as indicated on the slide, but a distorted juvenile of *Cyclammina complanata.*

Chapman & Crespin (1930) described *Cyclammina rotundata* and *C. longicompressa* from subsurface micaceous marls (Micaceous Marl Member of Carter 1964, pp. 22, 58, Table 1) now renamed the Metung Marl Member (Hocking 1976, p. 259) of the Lakes Entrance Formation. The association of *Cyclammina* species with *Victoriella conoidea* and *Almaena gippslandica* (Carter 1964, pp. 22, 56) establishes an Oligocene to Early Miocene age (Janjukian Stage) for the unit, *Globigerina euapertura* zone of Ludbrook & Lindsay (1969) equivalent to P21 (=N2) to N4 of Blow (1969).

Chapman & Crespin (1932) recorded *Cyclammina incisa* (Stache) from the same unit.

Parr (1938) briefly described *Cyclammina incisa* (Stache) from sediments he believed to be of Late Eocene age from deep borings in King's Park, Perth, but which are now defined as the King's Park Shale, of Palaeocene age (McGowran 1964).

Singleton (1941) erected the Anglesean Stage for "the interval of time represented by the deposition of the dark-coloured sands with *Cyclammina* of cliff sections between Anglesea and Point Addis", which he considered to be of Oligocene age. However, Singleton (p. 13 and correlation chart) correlated other not necessarily contemporaneous *Cyclammina*-bearing carbonaceous sands with those at Anglesea.

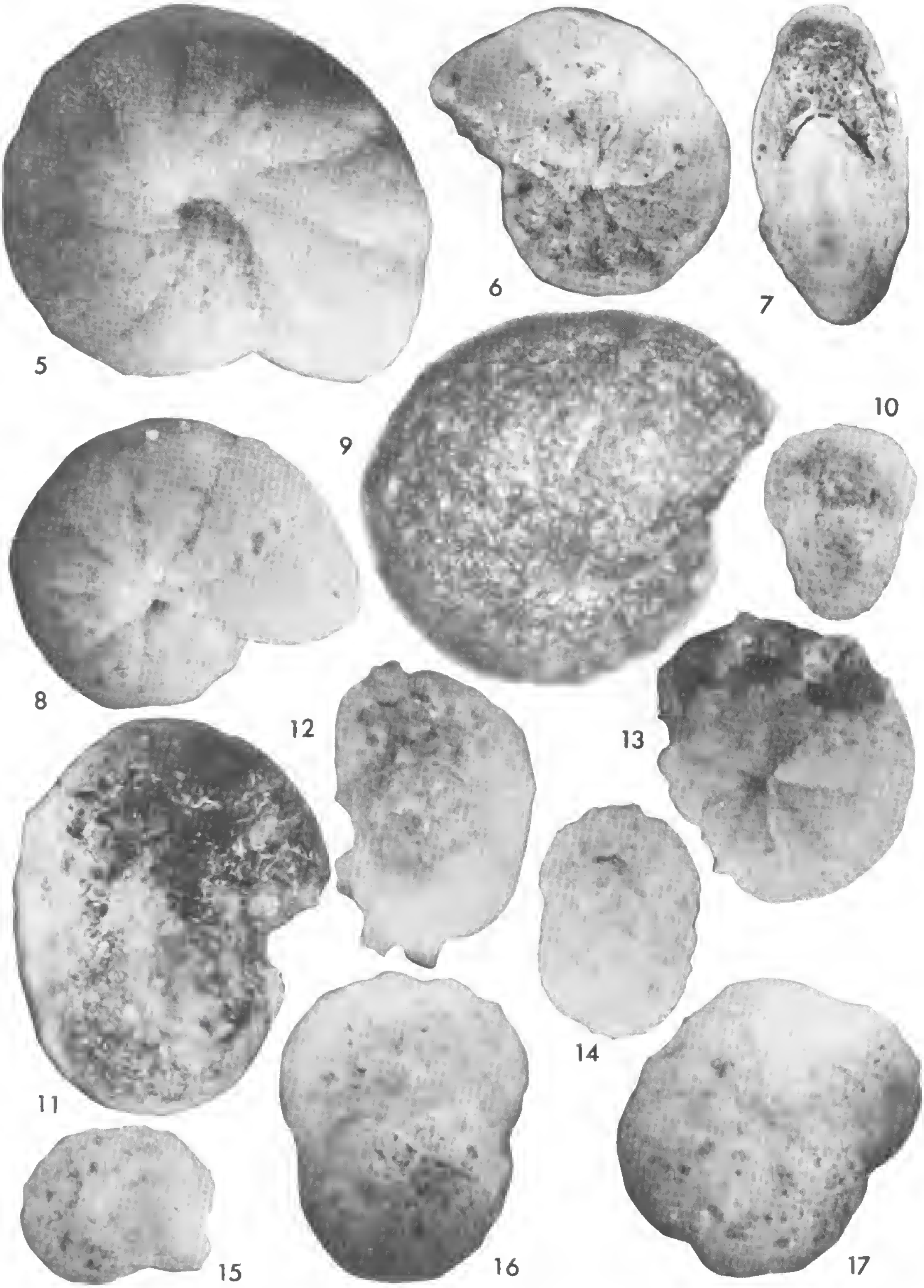
Crespin (1943) recorded in detail the distribution and stratigraphic range of *Cyclammina incisa, C. rotundata* and *C. longicompressa* (= *C. incisa*) in subsurface sediments of the Gippsland Basin, *Cyclammina incisa* being selected as the zone fossil for the Janjukian Lakes Entrance Formation in which it was said to be persistent (Crespin 1943, pp. 8, 10, 13, 78, Table 1).

Crespin (1950, p. 72, pl. 10, figs 3, 4, 5a, b) described species occurring in the stratotype Anglesean at Demon's Bluff. The specimen figured as *C. paupera* (pl. 10, fig. 4) appears to be an immature *C. incisa*, and not *C. paupera* as interpreted by Taylor (1965, p. 151, fig. 4 (1a, b)) and in the present paper.

Baker (1953) recorded *Cyclammina* from the Princetown Member of the Dilwyn Forma-

TABLE 1.
Analysis of specimens measured

Species	Specimens	Chambers in last whorl	Diameter	Average diameter	Thickness	Average thickness	Ratio diameter: thickness	Percentage of total 6–7	8	9	10	11	12	12+	Remarks
C. complanata	54	7–16	0.45–3.75	1.08	0.15–1.12	0.39	2.8:1	1.85	1.85	16.66	18.20	26.00	20.40	14.82	96% have 9 or more chambers
C. incisa	390	7–15	0.28–3.00	1.15	0.15–1.75	0.54	2.13:1	5.64	14.87	26.41	26.15	11.80	8.20	6.92	79% have 8–11 chambers
C. otwayensis	172 (+480)	7–11	0.35–0.80	0.64	0.15–0.50	0.30	2:1	16.30	29.70	39.50	10.50	4.00	—	—	69% have 8–9 chambers
C. paupera	52	7–11	0.33–0.75	0.52	0.12–0.25	0.20	2.6:1	3.85	26.92	32.69	28.84	5.77	1.92	—	88% have 8–10 chambers
C. rotunda	93	6–13	0.50–2.12	1.13	0.30–1.50	0.73	1.55:1	11.83	23.66	24.73	18.28	6.45	11.93	3.22	85% have 8–11 chambers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tion. According to Harris (1965, p. 78) palynological evidence indicated a Late Palaeocene age for this member, and the possibility of the microfloral zonule present in the upper part of the Dilwyn Formation being as young as Early Eocene was not excluded (Taylor in Singleton 1968, 1973, p. 116); Harris 1971, pp. 70, 78; Taylor 1971, p. 226). The Princetown Member contains *Planorotalites* cf. *pseudomenardii* (Taylor in Singleton 1968, 1973, p. 116) and a latest Palaeocene to Early Eocene age (latest P6 to P7) is indicated (McGowran et al. 1971, Enclosure 14.1).

Raggatt & Crespin (1955) defined the Demon's Bluff Formation in which *Cyclammina* was the dominant and abundant form in exposures of the formation between Torquay and Eastern View in the Torquay Basin.

From palynological data presented by Harris (1971, pp. 72, 84), the microflora of the Demon's Bluff Formation falls within his *Triorites magnificus* zonule, which in its full range is equivalent to upper *Globigerapsis index index* to "*Turborotalia*" *aculeata* planktonic foraminiferal zones of Ludbrook and Lindsay (1969) corresponding to P13 to P16 of Blow (1969) and of late Middle to Late Eocene age (McGowran et al. 1971, Enclosure 14.1). Singleton's (1968, 1973, p. 116) chart would indicate a Late Eocene age, P16 to P17, and Abele et al. (1976, p. 232) a Late Eocene to Early Oligocene age for the Anglesea Member.

Ludbrook (1963) reported *Cyclammina* as being well-represented in the early Tertiary of the Gambier Embayment.

Taylor (1965) in studies of subsurface sediments of the Port Campbell Embayment, claimed that the genus had been misinterpreted and that apparent labyrinthic internal structures were not primary morphological features but the result of replacement of agglutinating cement by pyrite, and that quartz plucking was responsible for a cancellate appearance of the wall surface (Taylor 1965, p. 9). Using evidence that the living *Cyclammina cancellata* Brady was restricted to depths greater than 200 metres and that the *Cyclammina*-bearing sediments of the Otway Basin were laid down under fairly shallow shelf to estuarine conditions, so that the presence of *Cyclammina* in the Dilwyn Formation would be contrary to environmental interpretations (p. 158), Taylor transferred the species previously recorded in *Cyclammina* to *Haplophragmoides*. Unfortunately, Taylor's reclassification was accepted by other workers such as McGowran (1965, p. 18), Singleton (1968, 1973, p. 117), Banner (1970, p. 277) and Harris (1971, pp. 80, 83, 84), and the significance of *Cyclammina* in the Australian early Tertiary was temporarily placed in abeyance. Taylor, however, demonstrated mainly from subsurface sections that the *Cyclammina* ("*Haplophragmoides*") species had characteristic stratigraphic ranges. In this he is supported in the present paper.

Ludbrook (1971) asserted that the species were correctly placed in *Cyclammina* by previous authors. McGowran (1973) recorded a *Cyclammina* facies in the Lacepede Formation. Lindsay & Bonnett (1973) recorded and figured "*Cyclammina*" cf. *incisa* from subsurface sediments of Oligocene age in the Waikerie area of the Murray Basin.

Cockbain (1974) described and figured, including a thin section, *Cyclammina incisa* from the Late Eocene Pallinup Siltstone, Plantagenet Group, southwestern Australia.

PLATE 1

Figs 5–8, 13. *Cyclammina incisa* (Stache). Fig. 5—GSSA Ff597, O.D.N.L. Mt Salt No. 1, 939–942 m, Dartmoor Formation, Palaeocene to Early Eocene, X46. Fig. 6—GSSA Ff596, E. & W.S. Kingston No. 3, 65.2–69.2 m, Lacepede Formation, Late Eocene, umbilical view, X30. Fig. 7—GSSA Ff596, E. & W.S. Kingston No. 3, 65.2–69.2 m, Lacepede Formation, Late Eocene, apertural view, X30. Fig. 8—GSSA Ff595, O.D.N.L. Mt Salt No. 1, 777–780 m, Dartmoor Formation, Palaeocene to Early Eocene, X50. Fig. 13—GSSA Ff603, O.D.N.L. Mt Salt No. 1, 750–753 m, Dartmoor Formation, Palaeocene to Early Eocene, natural dissection, view into chamber lumina showing hypodermal alveolae in walls of two chambers, X46.

Figs 9–12, 14–17. *Cyclammina rotundata* Chapman & Crespin. Fig. 9—GSSA Ff613, O.D.N.L. Mt Salt No. 1, 966–969 m, Dartmoor Formation, Palaeocene to Early Eocene, X50. Fig. 10—GSSA Ff612, B.P.N.L. Geltwood Beach No. 1, 454 m, Tartwaup Formation, Middle Eocene, X30. Fig. 11—GSSA Ff616c, Demon's Bluff Formation, Demon's Bluff, Late Eocene, showing very small areal apertures on the left side, X50. Fig. 12—GSSA Ff616b, Demon's Bluff Formation, Late Eocene, showing slight lip on aperture, X50. Fig. 14—GSSA Ff611, S.A.D.M. Waikerie Bore 28W, 146.3–147.8 m, Ettrick Formation, Oligocene, juvenile specimen showing short open aperture, X50. Fig. 15—GSSA Ff612, B.P.N.L. Geltwood Beach No. 1, 454 m, Tartwaup Formation, Middle Eocene, umbilical view, X30. Fig. 16—GSSA Ff612, apertural view, X50. Fig. 17—GSSA Ff612, umbilical view, X50.

TABLE 2.
Measurements of specimens sectioned

Reg. No. GSSA	Number whorls	Chambers in last whorl	Diameter mm	Thickness mm	Diameter initial chambers mm	Whorls in initial chambers	Wall thickness mm	Interseptal width of chamber mm	Last chamber lumen mm	Septal wall thickness mm	Mega- or micro-spheric	Vertical or equatorial section	Locality (see Fig.1)	depth m
C. complanata														
Ff619	3	15	2.88	1.00	1.25	2	0.38–0.5	0.10	0.75	0.60	micro-	E	15 cavings	651–653
Ff620			1.50	0.50			0.25					V	15 cavings	654–655
Ff623			1.96	0.75			0.25		0.50			V	15	411–415
Ff626	2½	10	0.75	0.30	0.75	2½		poor specimen, juvenile				E	17	881–884
Ff627	?4	11	0.70	0.30	0.70	3–4	0.08	0.05	0.30	0.05		E	17	881–884
Ff628	2	9	0.88	0.30	0.88	2	0.10	0.13	0.13	0.10	micro-	E	17	911–914
Ff629	3	11	0.75	0.25	0.75	3		poorly preserved, juvenile				E	17	914–917
Ff630	3	9	0.66	0.25	0.66	3		poorly preserved, juvenile				E	17	914–917
Ff631	2	11	1.00	0.50	1.00	2	0.13	0.13	0.13	0.05	?mega-	E	17	917–920
Ff645	3½	13	1.12	0.50	1.00	3	0.13	0.03	0.13	0.13		E	17	930–933
C. incisa														
Ff621	4	11	2.00		1.00	3	0.20	0.13	0.38	0.13	micro-	E	15	411–415
Ff632	?3	?11	1.75	0.80	1.00	2		poorly preserved			micro-	E	16	274–277
Ff633	4	15	2.88	1.25	1.50	3	0.45	0.20	0.35	0.13	micro-	E	4	
Ff634		13	2.75	1.75			0.38					V	4	
Ff635	4	15	2.55		1.0	3	0.60	0.20	0.38	0.20	micro-	E	5	
Ff641		10	1.75	1.12				poorly preserved			?micro-	E	3	
Ff642	3	8	0.75	0.37	0.75	3		juvenile			?	E	3	
Ff643			1.25				0.25		0.60		?	V	1	
Ff644	2	11	1.12				0.20	0.10	0.18	0.08	mega-	E	5	
Ff646	4	13	2.33		1.13	3	0.38	0.13	0.33	0.18	micro-	E	4	
C. otwayensis														
Ff636		11	0.62	0.29			0.05 (1)					V	21	298.7
Ff637	3	9	0.62	0.35	0.62	3	0.05 (2)	0.10	0.13	0.03	micro-	E	21	298.7
Ff647			0.80					poorly preserved			?	E	21	298.7
Ff648	2½	9	0.60		0.60	2½	0.05	0.13	0.10	0.04	mega-	E	21	298.7
C. paupera														
Ff649	4	8	0.55		0.04	2	0.03	0.15	0.13	0.03	micro-	E	21	298.7
C. rotundata														
Ff624			0.93	0.62			0.25	poorly preserved				E	5	
Ff625	3	?11	1.75		1.00	?3	0.60					E	5	
Ff638	4	11	1.25	0.75	0.62	3	0.25	0.13	0.18	0.10	micro-	E	15	262–265
Ff639		?11	1.66	1.12			0.25 (3)					V	8	12–21

(1), (2), (3) Thickness epidermis 0.025 mm.

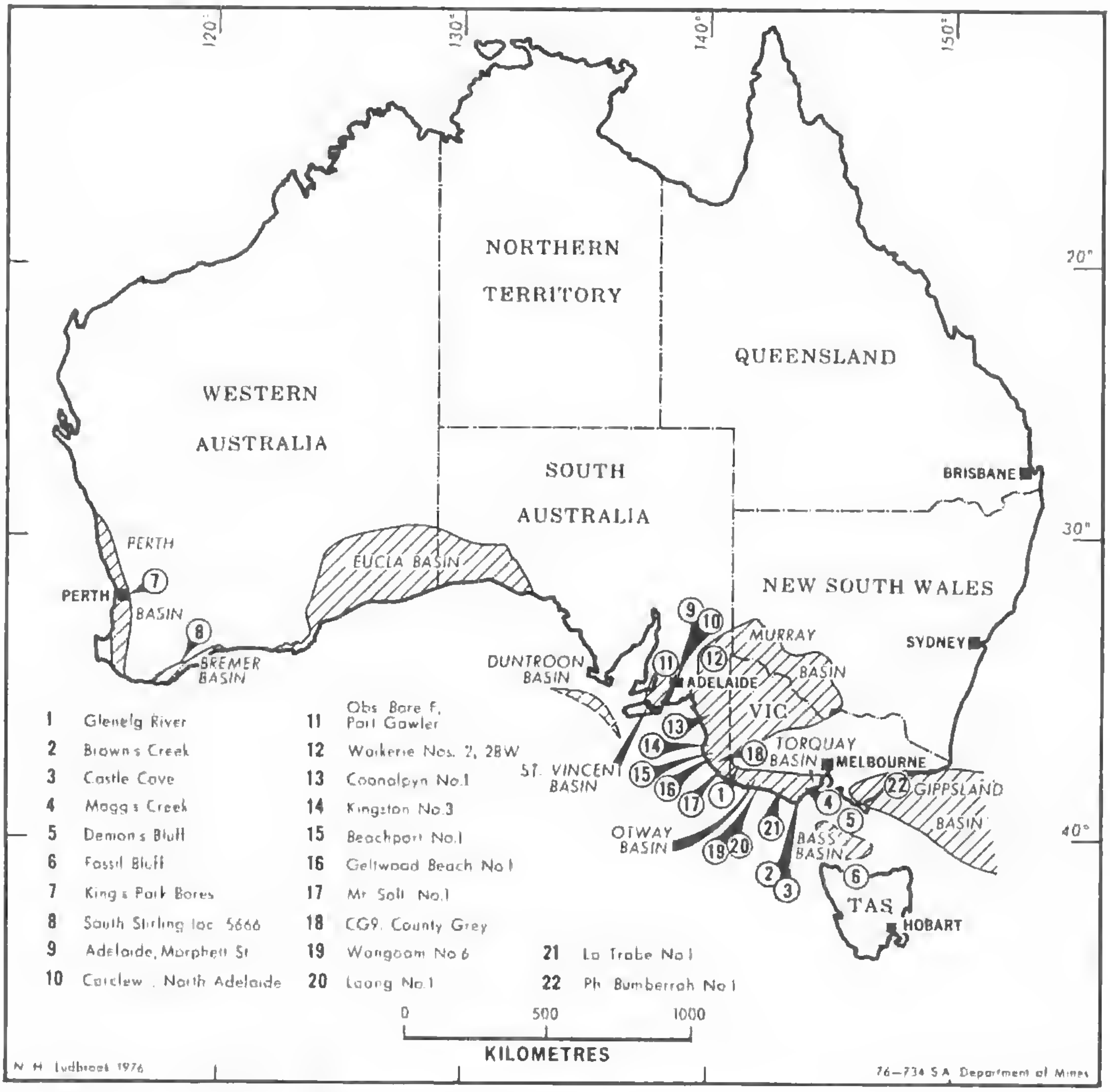


Figure 1. Map showing *Cyclammina* localities.

and recognised the pertinence of Robinson's (1970) observations to the apparent discrepancy between records of *Cyclammina* in early Tertiary shallow water deposits and the predominantly deep water depth range of the genus.

Quilty (1974) briefly described and figured, including a thin section, *Cyclammina* cf. *incisa* from Fossil Bluff, south of Table Cape, Tasmania.

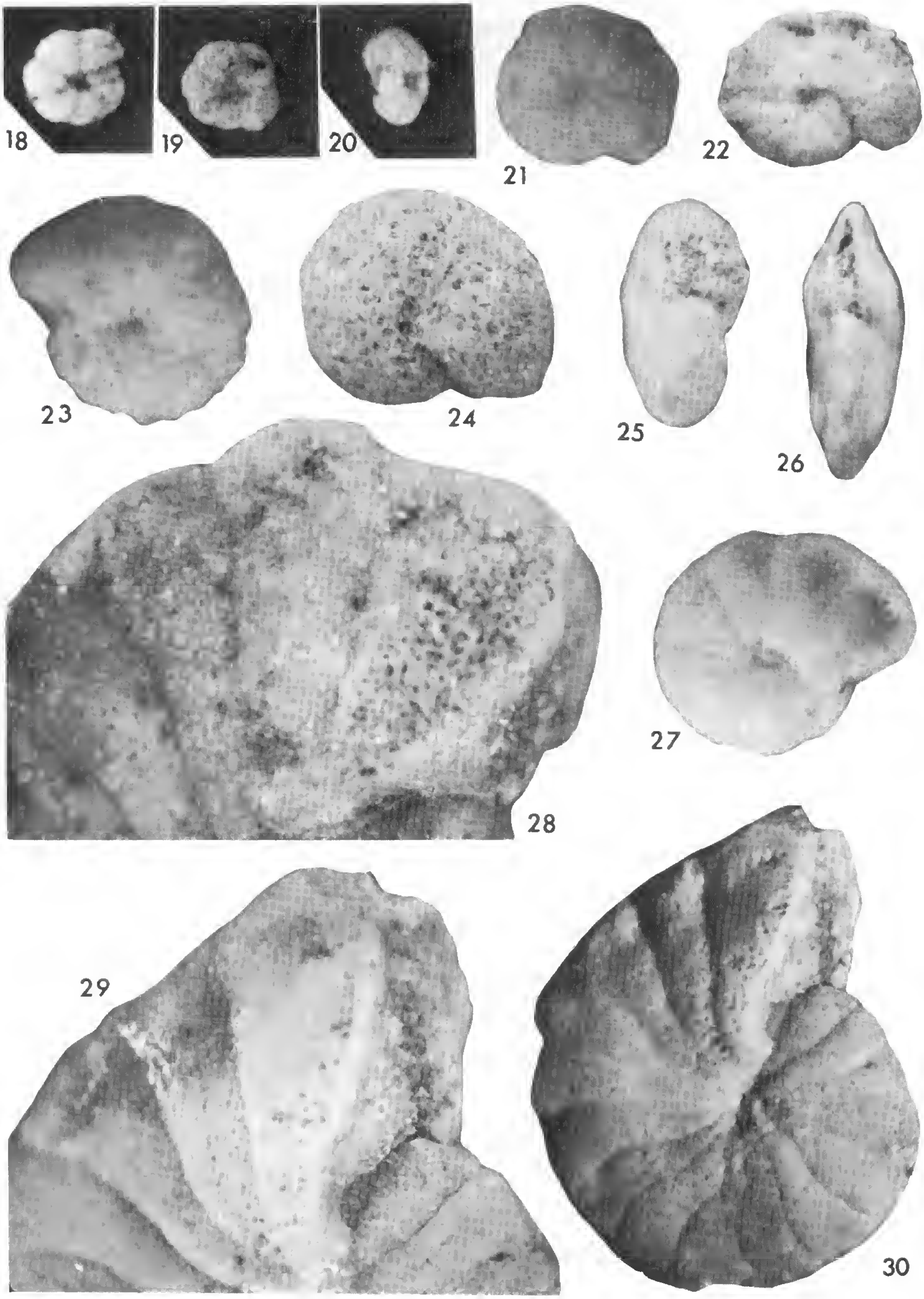
Source of material

Details of the localities shown in Figure 1 are as follows:

Outcrops

1. *Glenelg River*, 2.4 km downstream from Killara Bridge, 14 km SW of Casterton, HAMILTON 1:250 000 geological map sheet, 37°39′56″S, 141°17′23″E, Gambier Embayment, Otway Basin, base of Dartmoor Formation, Palaeocene to Early Eocene (see *Casterton* 1:63 360 geological map sheet).

2. *Brown's Creek*, between Rotten Point and mouth of Johanna River, 13.6 km NW of Cape Otway, COLAC 1:250 000 geological map sheet, 38°46′22″S, 143°23′14″E, Port Campbell Embayment, Otway Basin, base of Johanna River Sands, ?Palaeocene to Early Eocene (section described by Raggatt & Crespin 1955, p. 134).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3. *Castle Cove*, 10 km NW of Cape Otway, COLAC 1:250 000 geological map sheet, 38°47'18"S, 143°26'35"E, Port Campbell Embayment, Otway Basin, Johanna River Sands, ?Middle to Late Eocene (see Carter 1958, p. 13; Abele et al. 1976, p. 224).

4. *Mogg's Creek*, 4 km E of Eastern View, QUEENSCLIFF 1:250 000 geological map sheet, 38°28'15"S, 144°04'19"E, Torquay Basin, Demon's Bluff Formation, Late Eocene (section described by Raggatt & Crespin 1955, p. 108).

5. *Demon's Bluff, Anglesea*, QUEENSCLIFF 1:250 000 geological map sheet, 38°24'36"S, 144°11'39"E, Torquay Basin, Anglesea Member, Demon's Bluff Formation, Late Eocene (section described by Raggatt & Crespin 1955, pp. 113-117).

6. *Fossil Bluff, Table Cape*, BURNIE 1:250 000 geological map sheet, 40°58'55"S, 145°44'54"E, Bass Basin, Freestone Cove Sandstone, Table Cape Group, Early Miocene N4/5 (Quilty 1974, p. 33).

Boreholes and Wells

7. *King's Park Bores 1 and 2*, Perth, PERTH 1:250 000 geological map sheet, 31°58'S, 115°50'E, Perth Basin, King's Park Shale, Palaeocene (McGowran 1964).

8. *South Stirling*, Water Bore, Plantagenet Location 5666, near South Stirling, 20 km S of Stirling Range, MOUNT BARKER 1:250 000 map sheet, 34°36'S, 118°08'20"E, at 12-21 m depth, Bremer Basin, Pallinup Siltstone, Plantagenet Group, Late Eocene (Cockbain 1974).

9. S.A.D.M. *Adelaide*, New Morphett Street and Victoria Bridges, Bore 11, Adelaide Railway Station 25–25.6 m; Bore 12, south bank Torrens Lake 16.76–17 m; ADELAIDE 1:250 000 map sheet, 34°55'41"S, 138°35'02"E, St Vincent Basin, Adelaide Plains Sub-Basin, undifferentiated Tortachilla Limestone-Blanche Point Transitional Marl, Late Eocene (Lindsay 1969, pp. 54, 59).

10. S.A.D.M. *"Carclew", North Adelaide*, section TA749, hundred of Yatala, ADELAIDE 1:250 000 geological map sheet, 34°55'24"S, 138°35'02"E, 19.8–19.9 m, St Vincent Basin, Adelaide Plains Sub-Basin, Blanche Point Banded Marl, Late Eocene (Lindsay 1969, pp. 53, 58).

11. S.A.D.M. *Observation Bore F, Port Gawler*, T/A, hundred of Port Gawler, ADELAIDE 1:250 000 geological map sheet, 34°45'49"S, 138°27'E, 253–254.5 m, St Vincent Basin, Adelaide Plains Sub-Basin, Blanche Point Banded Marl, Late Eocene (Lindsay 1969, pp. 52, 55).

12. S.A.D.M. *Waikerie* Bore 2, section 692, hundred of Waikerie, 3.6 km SSW of Waikerie, 149 m; Bore 28W, section 553, hundred of Waikerie, 2.5 km southwest of Waikerie, 146–148 m, RENMARK 1:250 000 geological map sheet, 34°13'18"S, 139°57'30"E, Murray Basin, "glauconitic clay unit", Ettrick Formation, Oligocene (Lindsay & Bonnett 1973).

13. E. & W.S. *Coonalpyn No. 1*, section 56, hundred of Coneybeer, PINNAROO 1:250 000 geological map sheet, 35°41'05"S, 139°49'53"E, 69–71 m, 105–107 m, Murray Basin, Buccleuch Beds, A, B, Late Eocene (Ludbrook 1961, pp. 16, 17).

14. E. & W.S. *Kingston No. 3*, section 374, hundred of Lacepede, NARACOORTE 1:250 000 geological map sheet, 36°50'S, 137°51'E, 65.2–69.2 m, Gambier Embayment, Otway Basin, Lacepede Formation, Late Eocene (Ludbrook 1971, pp. 56, 58).

PLATE 2

Figs 18–20. *Haplophragmoides taylori* n.sp. Fig. 18—Holotype GSM 64829 (1), La Trobe No. 1 Well, 292.61 m, Dilwyn Formation, Palaeocene to Early Eocene, X48. Fig. 19—Paratype GSM 64829 (5) Wangoom No. 6, Core 12, 596–601 m, Dilwyn Formation, ?Early Eocene, umbilical view, X48. Fig. 20—Paratype GSM 64829 (5), apertural view, X48.

Figs 21, 22, 26, 27. *Cyclammina paupera* Chapman. Fig. 21—Topotype GSM 64828 (13), Brown's Creek, base of Johanna River Sands, ?Palaeocene to Early Eocene, X50. Fig. 22—GSSA Ff607 V.M.D. La Trobe No. 1, Core at 298.7 m, Dilwyn Formation, Palaeocene to Early Eocene, umbilical view, X50. Fig. 26—GSSA Ff616, V.M.D. La Trobe No. 1, Core at 298.7 m, Dilwyn Formation, Palaeocene to Early Eocene, apertural view, X90. Fig. 27—GSSA Ff650, O.D.N.L. Mt Salt No. 1, 954–957 m, Dartmoor Formation, Palaeocene to Early Eocene, X90.

Figs 23–25. *Cyclammina otwayensis* n.sp. Fig. 23—Holotype GSSA Ff608, Glenelg River, base of Dartmoor Formation, Palaeocene to Early Eocene, X50. Fig. 24—Paratype GSSA Ff609, V.M.D. La Trobe No. 1, Core at 298.7 m, Dilwyn Formation, Palaeocene to Early Eocene, X50. Fig. 25—Paratype GSSA Ff610, V.M.D. La Trobe No. 1, Core at 298.7 m, Dilwyn Formation, Palaeocene to Early Eocene, X50.

Figs 28–30. *Cyclammina complanata* Chapman. Fig. 28—GSSA Ff593, S.E.O.S. Beachport No. 1, 602–604 m, ?cavings from Dartmoor Formation, Palaeocene, showing appearance of distal ends of alveolae as seen through the epidermis and after erosion of epidermis, X40. Fig. 29—GSSA Ff594, S.E.O.S. Beachport No. 1, 661–663 m, ?cavings from Dartmoor Formation, Palaeocene, showing areal apertures and thin, fine-grained epidermis with distal ends of alveolae exposed by erosion of epidermis, X37. Fig. 30—GSSA Ff594, X26.

TABLE 3

Stratigraphic distribution and faunal association of *Cyclammina* species.

Species	Size	Chambers	PALAEOCENE TO EARLY EOCENE				MIDDLE TO LATE EOCENE							OLIGOCENE			MIOCENE
			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
C. complanata	large	15–16	—	X, b	—	X	—	—	—	—	—	—	—	—	—	—	—
C. incisa	large	8–11	?	X	X, p, b	—	X	—	X, a	X, p, b	X, p, b	—	X, p, b	X	X, p, b	X, p, b	X, p, b
C. otwayensis	small	8–9	X, a	X	—	D	—	X	—	—	—	—	—	—	—	—	—
C. paupera	small	8–10	X, a	X	—	X	—	—	—	—	—	—	—	—	—	—	—
C. rotundata	large	8–11	X	X	—	—	X	—	X, a	—	X, p, b	X, p, b	—	X	X, p, b	X, p, b	?

A. Dilwyn Formation
B. Dartmoor Formation
C. King's Park Shale
D. Johanna River Sands at Brown's Creek
E. Johanna River Sands at Castle Cove
F. Burrungule Member, Tartwaup Formation
G. Demon's Bluff Formation
H. Lacepede Formation

I. Gambier Limestone
J. Tortachilla Limestone—Blance Point Marls
K. Buccleuch Beds, A, B
L. Pallinup Siltstone
M. Ettrick Formation
N. Lakes Entrance Formation
O. Freestone Cove Sandstone

X. *Cyclammina*
a. agglutinated foraminifers
p. planktonic foraminifers
b. benthonic foraminifers

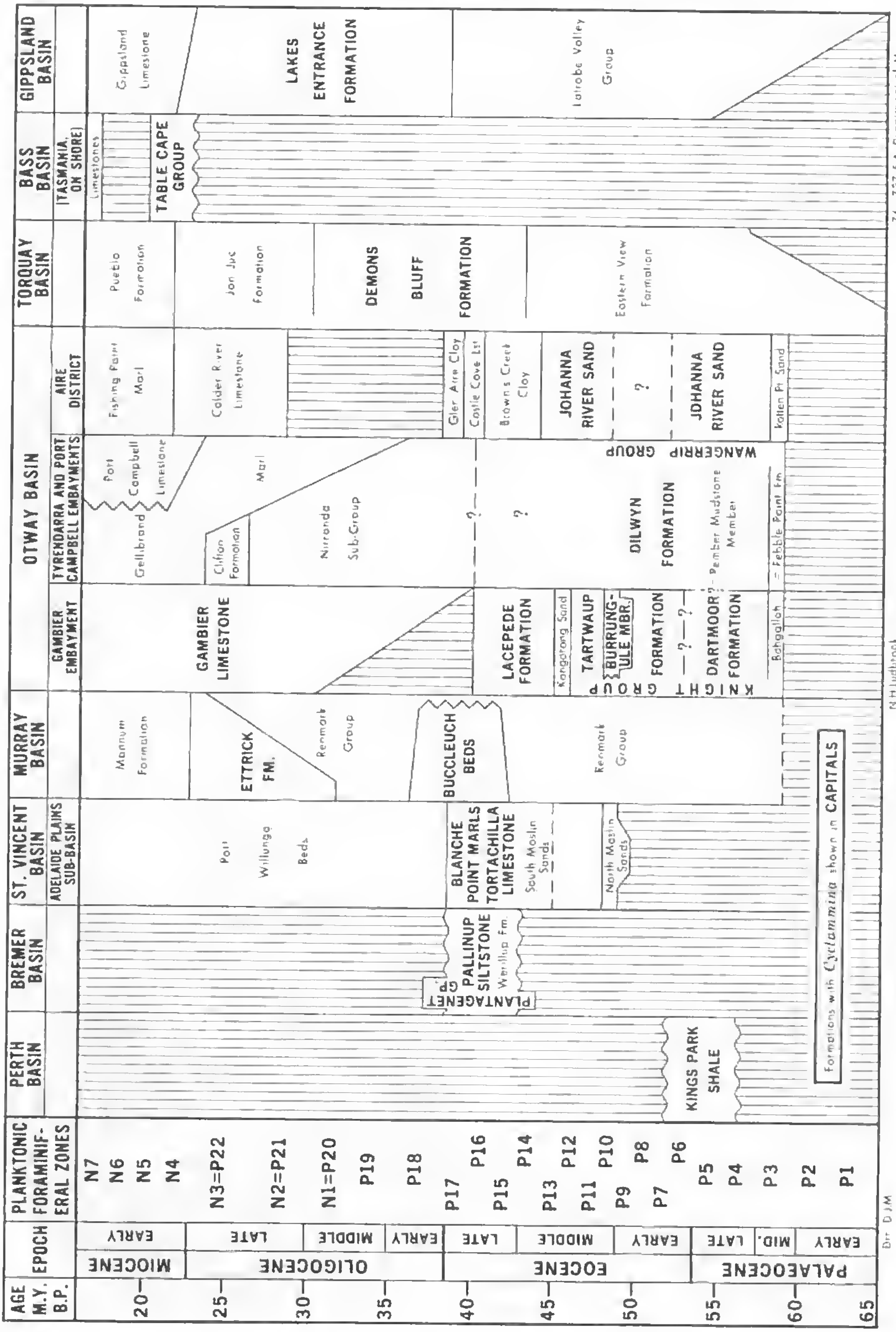
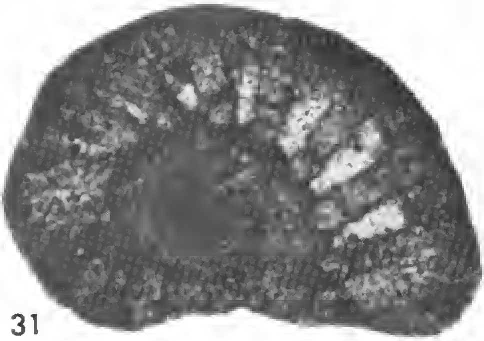


Figure 2. Correlation of *Cyclammina-bearing* formations in southern Australia.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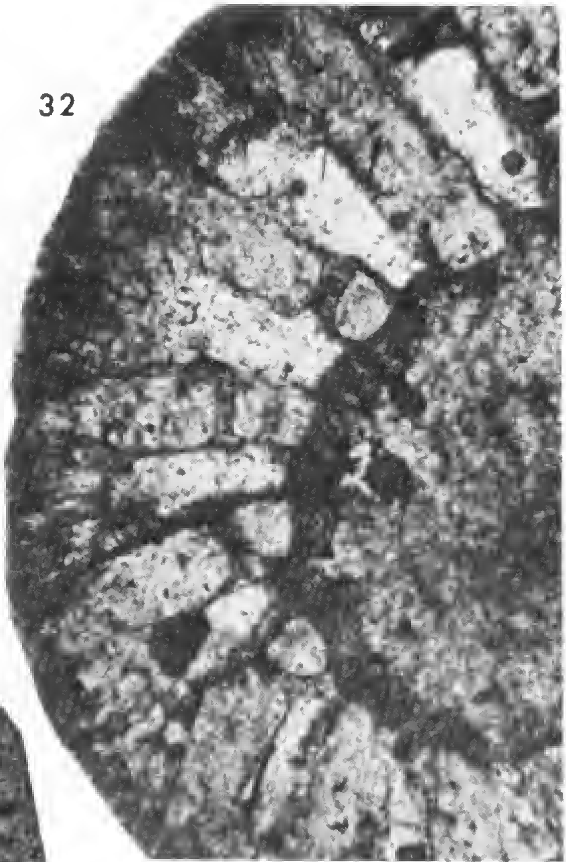
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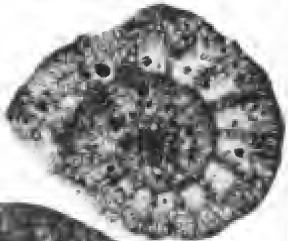
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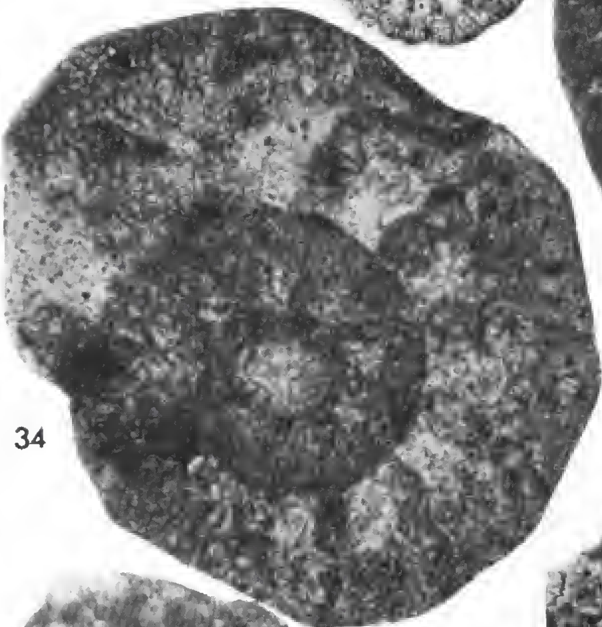
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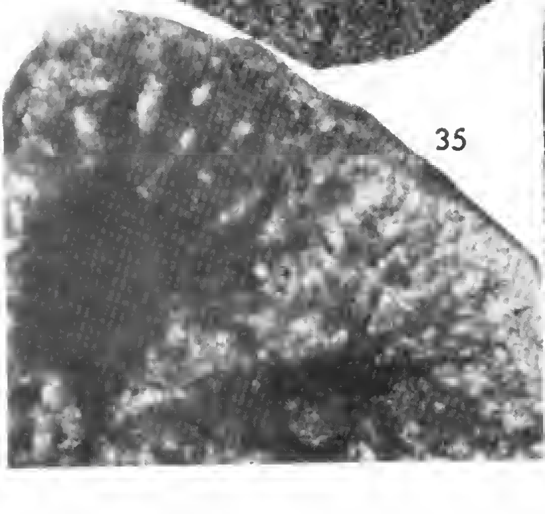
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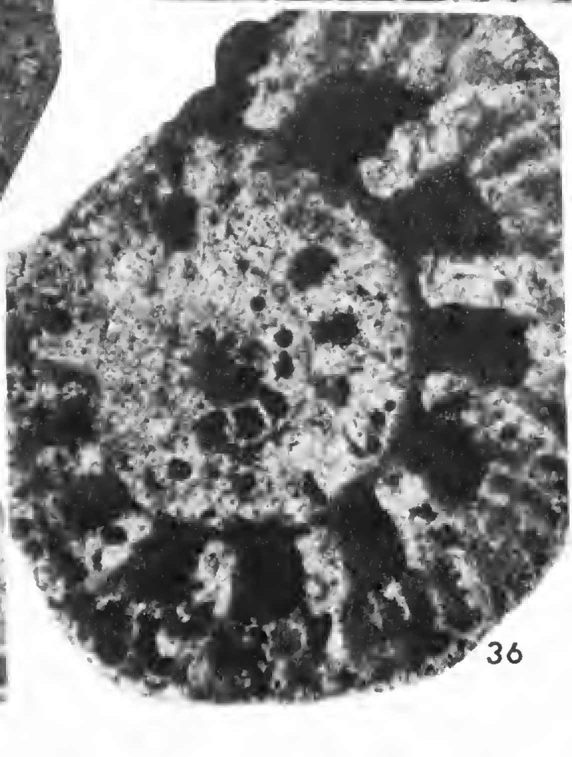
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15. S.E.O.S. *Beachport No. 1*, section 20, hundred of Lake George, PENOLA 1:250 000 geological map sheet, 37°26′55″S, 140°02′15″E, Gambier Embayment, Otway Basin; 238–240 m Gambier Limestone, Late Eocene; 259–271 m Lacepede Formation, Late Eocene; 311–417 m Tartwaup Formation, Middle Eocene; 543–546 m Dartmoor Formation, Palaeocene to Early Eocene; 602–663 m ?cavings from overlying Dartmoor Formation (Ludbrook 1971, pp. 52, 56).

16. B.P.N.L. *Geltwood Beach No. 1*, section 157, hundred of Mayurra, PENOLA 1:250 000 geological mapsheet, 37°39′44″S, 140°14′35″E, Gambier Embayment, Otway Basin; 238–277 m Gambier Limestone, Late Eocene; 454 m Tartwaup Formation, Middle Eocene (Ludbrook 1971, pp. 52, 56).

17. O.D.N.L. *Mt Salt No. 1*, section 783, hundred of MacDonnell, PENOLA 1:250 000 geological map sheet, 37°57′25″S, 140°37′43″E, Gambier Embayment, Otway Basin, 585–954 m Dartmoor Formation, Palaeocene to Early Eocene; 954–972 m Bahgallah Formation, Palaeocene (Ludbrook 1971, pp. 52, 56).

18. S.A.M.D. *C.G.9*, County Grey lignite investigations, section 819, hundred of Young, PENOLA 1:250 000 geological map sheet, 37°44′49″S, 140°37′54″E, Gambier Embayment, Otway Basin, 28.96–29.26 m, Burrungule Member, Tartwaup Formation, Middle Eocene (Harris 1966, p. 2, 1971, p. 81).

19. V.M.D. *Wangoom No. 6*, Warrnambool, water exploration bore, PORTLAND 1:250 000 geological map sheet, 38°23′S, 142°29′18″E, Tyrendarra Embayment, Otway Basin, Core 12, 596–601 m Dilwyn Formation, ?Early Eocene (Glenie 1971, Enclosure 13.6).

20. V.M.D. *Laang No. 1*, 28 km east of Warrnambool, water exploration bore, COLAC 1:250 000 geological map sheet, 38°23′S, 142°48′33″E, Tyrendarra Embayment, Otway Basin, Core 12, 654–656 m, Nirranda Sub-Group, Narrawaturk Marl, Late Eocene (Taylor 1965, fig. 5, p. 155; Glenie 1971, Enclosure 13.2).

21. V.M.D. *La Trobe No. 1* Princetown, COLAC 1:250 000 geological map sheet, 38°41′49″S, 143°10′49″E, Port Campbell Embayment, Otway Basin, 292.6–298.7 m Dilwyn Formation, Palaeocene to Early Eocene (Taylor 1965, Fig. 5, p. 155; Glenie 1971, Enclosure 13.2).

22. P.A.C. *No. 1 Bore Parish of Bumberrah*, Metung, BAIRNSDALE 1:250 000 geological map sheet, 37°53′34″S, 147°50′14″E, Gippsland Basin, 394.7 m Lakes Entrance Formation, Oligocene.

Stratigraphic utility

Allowing for differences in nomenclature and taxonomic interpretation, Table 3 gives support to the data presented by Taylor (1965, p. 155, fig. 5). Palaeocene to Middle Eocene faunas are represented by three species: *C. complanata*, *C. otwayensis* and *C. paupera*. These species are not found in Late Eocene to Miocene sediments where only the long-ranging *C. incisa* and *C. rotundata* occur.

The stratigraphic relationships of the *Cyclammina*-bearing formations are shown in Figure 2. For the Otway Basin, the chart has been considerably simplified and for the Aire District slightly modified from those presented by Abele et al. (1976) which should be consulted for greater detail and for illustration of the diachronous relationships between most of the formations. The position of the Glen Aire Clay approximates to that expressed by Ludbrook & Lindsay (1969, p. 371). The name "Knight" (Sprigg 1952; Sprigg & Boutakoff 1953) has been retained for the Group of Early Tertiary non-marine and paralic sediments of the Gambier Embayment, in conformity with its continued use by the South Australian Department of Mines in hydrogeological studies of the Embayment and its use by most authors (Kenley, Rochow, Ludbrook, Taylor) in the Bulletin on the Otway Basin (Wopfner & Douglas 1971) and on the geological maps accompanying the Bulletin. It is beyond the scope of the present paper to disentangle the nomenclatural priorities of the units comprising the Knight and Wangerrip (Baker 1950) Groups which have already been discussed at some length by Kenley (1971), Glenie (1971)

PLATE 3

Figs 31–35. *Cyclammina incisa* (Stache). Fig. 31—GSSA Ff621, Demon's Bluff Formation, Demon's Bluff, Late Eocene, microspheric specimen, equatorial section, X30. Fig. 32—GSSA Ff621, enlargement of part of last whorl showing hypodermal and septal alveolae, X75. Fig. 33—GSSA Ff633, Demon's Bluff Formation, Mogg's Creek, Late Eocene, microspheric specimen, equatorial section, X13. Fig. 34—GSSA Ff644, Demon's Bluff Formation, Demon's Bluff, Late Eocene microspheric specimenn, equatorial section, X75. Fig. 35—GSSA Ff632, B.P.N.L. Geltwood Beach No. 1, 274–277 m, base of Gambier Limestone, Late Eocene, part of 2 chambers of collapsed specimen, equatorial section, X75.

Fig. 36. *Cyclammina rotundata* Chapman & Crespin (?*C. incisa* (Stache). GSSA Ff638, S.E.O.S. Beachport No. 1, 262–265 m, Lacepede Formation, Late Eocene, microspheric specimen, equatorial section, X75.

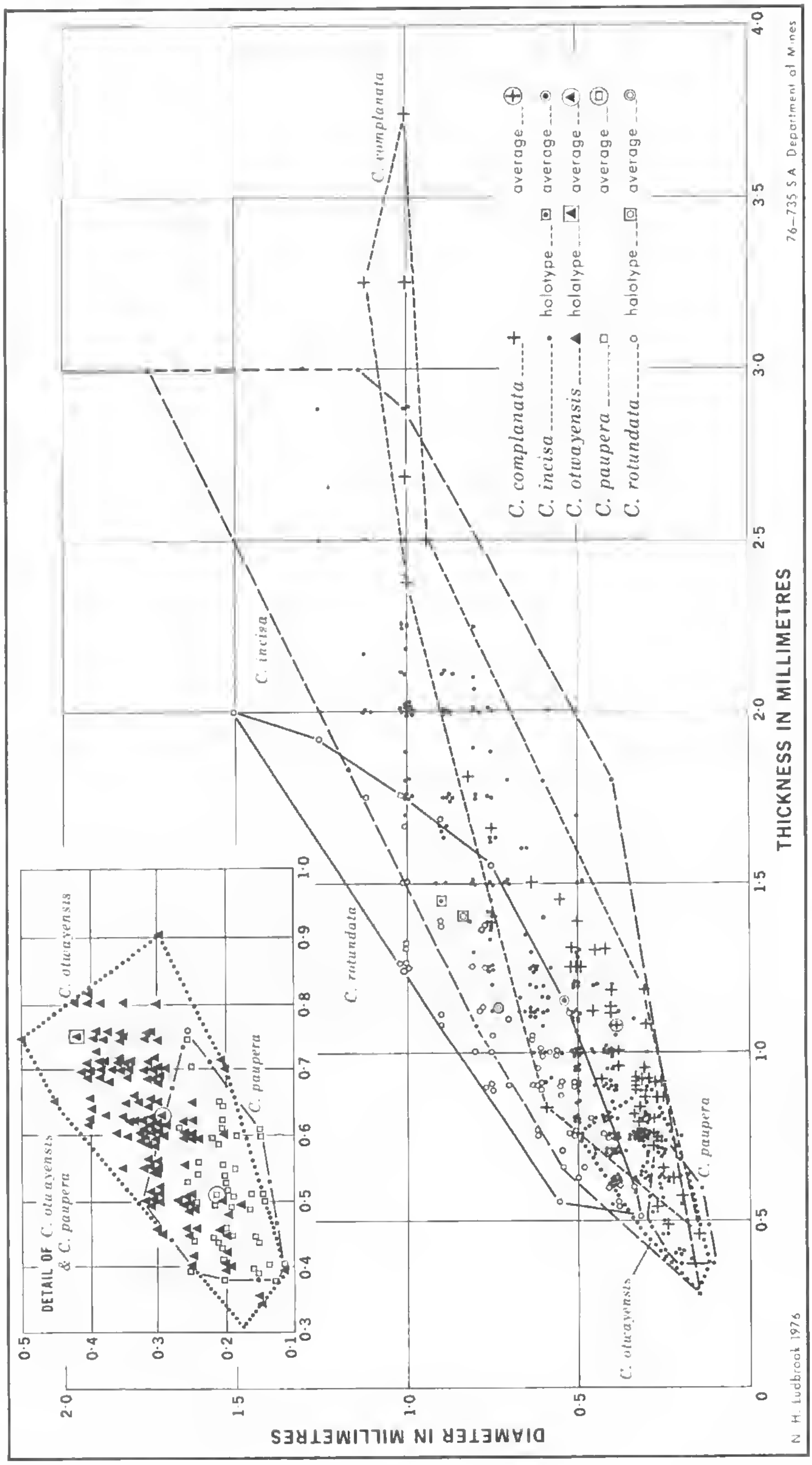


Figure 3. Scatter diagram of dimensions (diameter/thickness) of *Cyclammina* spp.

and Abele et al. (1976). Until the lithological and palaeontological relationships of all the units of the two groups are fully defined, it seems desirable to retain the nomenclature current for the Gambier and Port Campbell Embayments as shown in Figure 2.

Sectioning techniques

On the whole, specimens of *Cyclammina* from the southern Australian Tertiary are abundant and reasonably well-preserved. Distortion is relatively uncommon, and, apart from pyrite infilling, most tests have not been subjected to chemical action such as the secondary silicification described by Serova (1964). They are, nonetheless, difficult to section since the original cementing material was very thin, apparently organic (see pl. 4, fig. 43), and usually not preserved at all, particularly in outcrop specimens. Great care has to be exercised to avoid quickly reducing the specimen to an unrecognisable mass of quartz grains.

Serova (1964) distinguished between half sections or "grinds" (shlifovaniya) achieved by grinding down to the equatorial plane so that the internal structures are viewed in direct light (see Serova 1964, pls. 2 and 3), and thin sections (shlify) completed in the normal way by turning the specimen over and grinding the other side, the result being viewed by transmitted light (see Serova pls. 4 to 7).

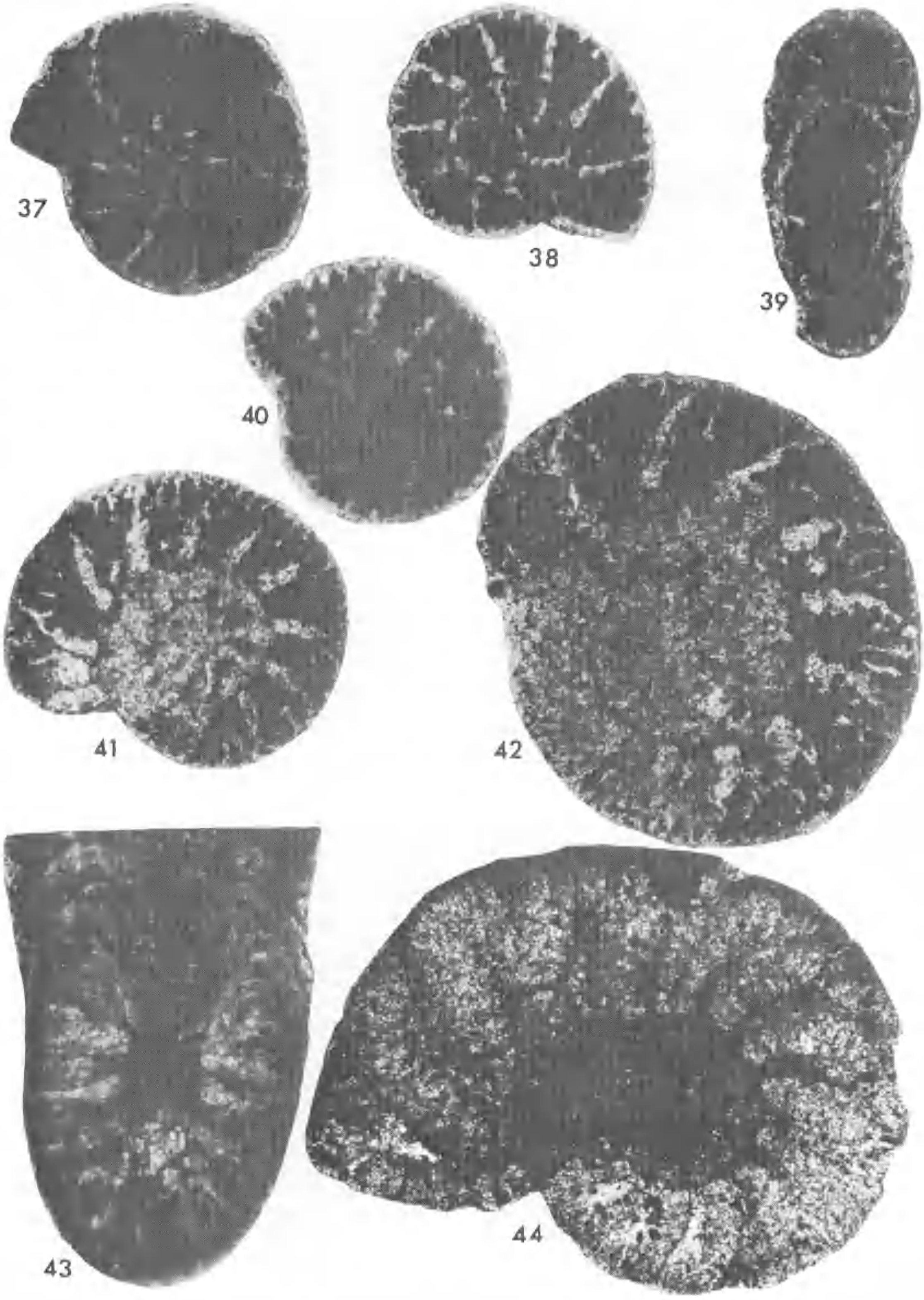
Taylor's figures (1965, p. 146, fig. 2) were drawn from dissected specimens (b) or "grinds" (a, c, d, "thick sections" of Taylor). No thin sections were cut.

The first problem encountered in sectioning is to keep the specimens intact and to prevent the agglutinated quartz grains from dispersing during the grinding process. Sectioning was done under the microscope, using one ground glass slide, with or without grinding powder, to grind the specimen mounted in Lakeside Cement on the other. The specimen was kept under constant observation during grinding, and at the first sign of a break through the cement to the test wall, the slide was reheated and the cement redistributed over the specimen by fine needle, filling any exposed cavities. This method of recementation was continued throughout the sectioning process, and turning the specimen over for grinding was done while the specimen was completely immersed in the heated mounting medium. At no stage was grinding done on uncemented test wall or on empty chamber lumina. Any surplus cement was removed when sectioning was completed and a drop of Xam placed on the specimen before covering with the cover slip. The most successful sections were those of specimens in which the organic lining of the chambers and alveolae were preserved (pl. 4, fig. 43) or where the chamber lumina and alveolae had been filled with pyrite and organic material (pl. 4, figs 37–42). No distorted specimens were used.

Morphology

Species show a wide range of development from the quite simple to non-alveolar structure of *Cyclammina paupera* to the highly-developed alveolar structure of *C. complanata*. Both of these extremes are present in Palaeocene sediments, and the only evidence of evolutionary development is that both the simple and the highly-developed forms do not persist beyond the Middle Eocene. The internal structures become clear only when thin sections are cut, though SEM photographs are valuable aids. Externally, species can be quite difficult to separate, as they almost all appear to intergrade. Considered at the adult well-developed end of the dimensional range, species are fairly readily separated from one another, but some populations contain a high percentage of immature individuals which, without the aid of thin sections, are specifically identifiable with only a mild degree of confidence. The overlap of species determined on their external features and plotted according to their relative dimensions (diameter/thickness) is clear from Figure 3, and the overlap of three of the species when the average diameter of the measured specimens is plotted against the number of chambers in the last whorl (Fig. 4).

Overlap is particularly the case with *C. incisa* and *C. rotundata*, which invariably occur together, and with *C. complanata* and *C. incisa*, which frequently occur together. As specimens identified as *C. incisa* occur over the whole stratigraphic range (Palaeocene to Miocene) of fossil *Cyclammina* in southern Australia and it is not practicable to cut thin sections to confirm the identity of all the specimens, its range may perhaps be open to question; the species has a known range of Eocene and Oligocene in New Zealand (Hornibrook 1971). *C. incisa* has been described as a "common Oligo-Miocene species of the circum-Pacific region" (Chang 1953) and recorded by several authors from the northern Pacific margin (Asano 1951, p. 6, figs 18, 19; Voloshinova & Budasheva 1961, p. 207, pl. 10, figs 1a, 1b, 3a, 4a,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4b; Chang 1953, p. 34, pl. 3, figs 3–10; Chang 1956, pl. 1, figs 6–8), but it has not been possible in the present study to confirm these records.

Diagnostic external characters

Measurable parameters are tabulated in Table 1 and shown graphically in Figures 3 and 4. The 172 specimens of *C. otwayensis* measured are representative of some 600 individuals all of approximately the same dimensions.

C. complanata has a large, flattened, discoidal test, partly evolute, with 15 to 16 chambers in the last whorl of the fully-grown adult and slightly sinuate sutures. It has a thin epidermis through which the alveolar hypodermal structure appears as a fine punctate to vermiform pattern (pl. 2, figs 28, 29). The apertural face is high, laterally flattened, with large supplementary apertures (pl. 2, figs 29, 30).

C. incisa when fully developed and undistorted has a moderately large biconvex involute test compressed at the periphery with 11 to 12 chambers in the last whorl, straight sutures, and a fine-grained epidermis with scattered large quartz grains. The apertural face is moderately high and covered with coarse quartz grains. Supplementary areal apertures are sometimes visible between the grains (pl. 1, fig. 7, pl. 6, figs 47–49).

C. otwayensis is a small, biconvex, rather inflated species with usually 8 to 9 chambers in the last whorl, a thin epidermis through which the distal ends of the alveolae are visible in 2 or 3 radiating series in each chamber. The apertural face is a fairly high rounded arch; small supplementary areal apertures are sometimes visible.

C. paupera is conspicuous in a population as a small, flattened, biconvex, commonly collapsed pauperate test with 8 to 10 chambers in the last whorl and a very fine-grained chamber wall. Alveolae are visible through the epidermis in the holotype and topotypes, but more commonly the alveolar hypodermis appears not to have developed (pl. 4, fig. 37). It would appear to be a primitive type of *Cyclammina* similar to the small species close to *C. elegans* figured by Banner (1970, pl. 13, figs 1, 1a), notable for the absence of a supra-apertural zone.

C. rotundata is a large, inflated species, with a coarse-grained chamber wall and 8 to 11 chambers in the last whorl of the fully-grown adult. The apertural face is a low broad arch at all stages of development (pl. 1, figs 10, 11, 12, 14, 16); areal apertures are frequently visible between the the coarse quartz grains which cover the face (pl. 1, fig. 11).

Diagnostic internal characters

Parameters measurable from thin sections are shown in Table 2.

Almost the complete range of morphological variation illustrated by Banner (1970, pl. 13) is present in the five species. The structure of the hypodermis of southern Australian *Cyclammina* is alveolar, as described for the type species *Cyclammina cancellata* Brady by authors such as Bronnimann (1951), Serova (1964) and Banner (1970), and not labyrinthic as the genus has been conventionally described (e.g. by Loeblich and Tappan 1964). The septal walls are perforated by septal areal

PLATE 4

Fig. 37. *Cyclammina paupera* Chapman, GSSA Ff649, V.M.D. La Trobe No. 1, 298.7 m Dilwyn Formation, Palaeocene to Early Eocene, microspheric specimen; the black areas are pyrite. X75.

Figs 38–40. *Cyclammina otwayensis* n.sp. Fig. 38—GSSA Ff648, V.M.D. La Trobe No. 1, 298.7 m, Dilwyn Formation, Palaeocene to Early Eocene, megaspheric specimen; black areas pyrite, X75. Fig. 39—GSSA Ff636, V.M.D. La Trobe No. 1, 298.7 m, Dilwyn Formation, Palaeocene to Early Eocene, vertical section; black areas pyrite, X75. Fig. 40—GSSA Ff637, V.M.D. La Trobe No. 1, 298.7 m, Dilwyn Formation, Palaeocene to Early Eocene, microspheric specimen; black areas pyrite, X75.

Figs 41–44. *Cyclammina complanata* Chapman. Fig. 41, GSSA Ff627, O.D.N.L. Mt Salt No. 1, 881–884 m, Dartmoor Formation, Palaeocene to Early Eocene, juvenile specimen; black areas pyrite, X75. Fig. 42—GSSA Ff631, O.D.N.L. Mt Salt No. 1, 917-920 m, Dartmoor Formation, Palaeocene to Early Eocene, juvenile, X75. Fig. 43—GSSA Ff623, S.E.O.S. Beachport No. 1, 411-414 m, Tartwaup Formation, Middle Eocene, part of vertical section showing organic lining of alveolae, some pyrite in lumina and openings of alveolae into chamber lumina, but alveolae mostly free of pyrite, X75. Fig. 44—GSSA Ff619, S.E.O.S. Beachport No. 1, 651–652 m, ?cavings from Dartmoor Formation, Palaeocene, microspheric specimen, equatorial section, alveolae mostly free of pyrite which is in the form of scattered small grains and one small aggregate indicated by the black patch between the tenth and eleventh chambers of the last whorl, X30.

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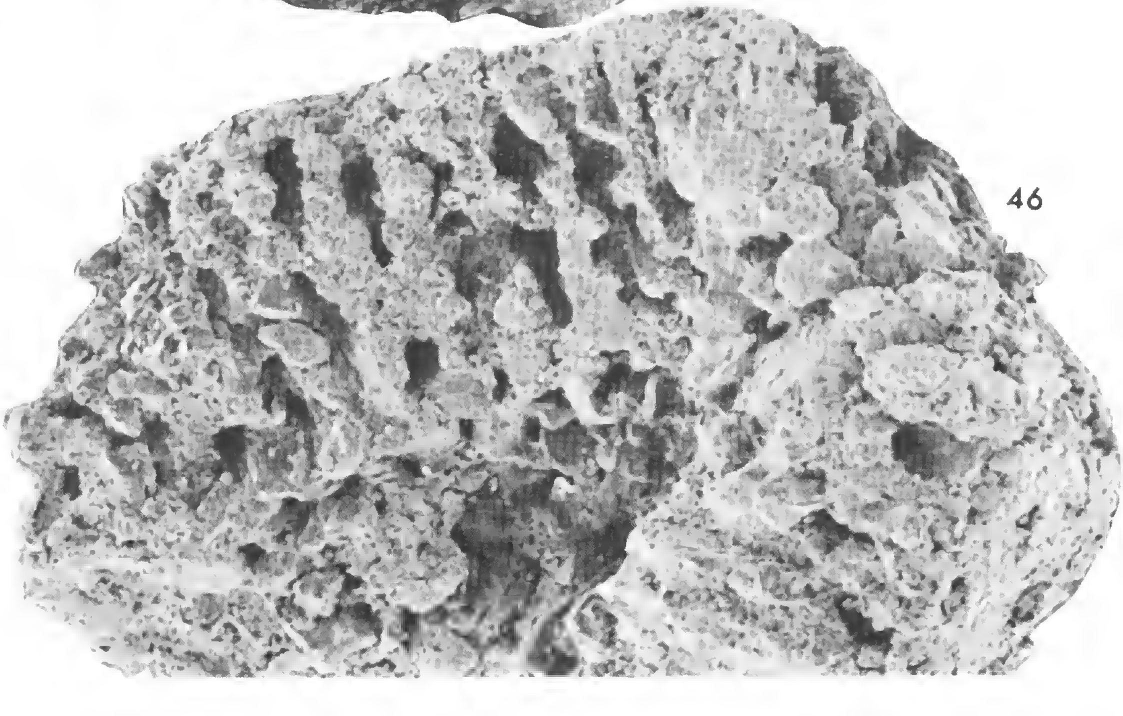

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apertures (pl. 3, fig. 32) similar to those illustrated for *Cyclammina* cf. *elegans* Cushman & Jarvis (Banner 1970, pl. 13, fig. 1a).

Each species has a distinctive alveolar pattern when fully developed, although there is the same range of intergradation as that presented by the external features.

C. paupera is a primitive type with a thin epidermis and a simple alveolar or non-alveolar hypodermis; the chamber lumina are widely open and in successive whorls are only slightly, if at all, offset as shown in equatorial section where the overall pattern is of unbroken radii (pl. 4, fig. 37). *C. paupera* appears to be of the type of *Cyclammina* cf. *elegans* Cushman & Jarvis as illustrated by Banner (1970, pl. 13, figs 1, 1a).

C. incisa is similar in structure to the type species *C. cancellata* Brady. The chamber lumina are widely open, separated by rather massive septal walls about equal in width to the interseptal width of the chamber lumina (pl. 3, figs 31–34 and Cockbain 1974, fig. 67C). The alveolar pattern of the hypodermis is somewhat more advanced than that of *C. cancellata*, consisting of simple, more-or-less parallel tubes opening into the chamber lumina (pl. 3, fig. 33; pl. 5, fig. 46; pl. 7, fig. 50) and tending to bifurcate beneath the epidermis (pl. 3, fig. 32). The alveolae, chamber, lumina and septal areal apertures are lined with organic material (pl. 3, fig. 32), which, it is assumed, acted also as cement in the chamber and septal walls.

C. rotundata appears to be a variant of *C. incisa* characterized by the development of very thick walls and reduced chamber lumina. In fully developed specimens the alveolae are fine, thin, more or less parallel tubes.

C. otwayensis has a relatively simple pattern, with alveolae radiating from the chamber lumina in series of 2 or 3 per chamber and bifurcating below the relatively thick, simple epidermis (pl. 4, figs 38, 40).

C. complanata is a highly complex form, with thin epidermis, thick alveolar hypodermis, thick septal walls penetrated by areal apertures and much reduced chamber lumina. The alveolae are lined with pseudochitin (pl. 4, figs 43, 44).

The nature of the organic cement is not known for any species. Staining did not reveal any calcite, as also found by Murray (1973a), and pyrite is present as an infilling of the chamber lumina and alveolae. Hedley (1963) described the cement of living agglutinated foraminifers as an acid mucopolysaccharide with organically bound iron, the cement being reinforced in *Cyclammina* by incorporating ferric iron. The presence of iron in any cement surviving the processes of fossilization could not be confirmed.

Palaeogeographical and palaeoecological interpretations

Sediments containing *Cyclammina* along the margin of southern Australia were deposited mainly during the early stages of the final separation of Australia from Antarctica and the development of the Southeast Indian (Southern) Ocean. Rifting was preceded by the extrusion during the Middle Jurassic of tholeiitic dolerites and basalts in Tasmania, Antarctica and Kangaroo Island (McDougall & Wellman 1976). The Otway Basin was initiated in the Late Jurassic or Early Cretaceous by the opening of a long, deep trough ("Otway Rift Valley" of Griffiths 1971, p. 77) into which a great thickness of non-marine clastic sediments, mainly feldspathic and lithic greywackes, was deposited. This was followed by continued subsidence and sporadic marine incursions in the Gambier and Port Campbell Embayments during the Late Cretaceous and Palaeocene and into the Eocene.

According to Weissel & Hayes (1972), the oldest lineation identified in the Southeast Indian (Southern) Ocean is anomaly 21, the age of which is 54 m.y. B.P. or anomaly 22 (56.5 m.y. B.P.), so that the formation of the normal oceanic crust which recorded the magnetic lineations began in the Late Palaeocene to Early Eocene about 55 million years ago.

Rifting and later patterns of sedimentation were diachronous events progressive from west to east (Griffiths 1971, p. 77). Limited marine

PLATE 5

Fig. 45. *Cyclammina incisa* (Stache), NZGS F101071, King's Park Bore No. 2, King's Park Shale, Palaeocene, X65.

Fig. 46. *Cyclammina incisa* (Stache), NZGS F100894, Demon's Bluff, Demon's Bluff Formation, Late Eocene, section through chamber wall and chamber lumen, X155.

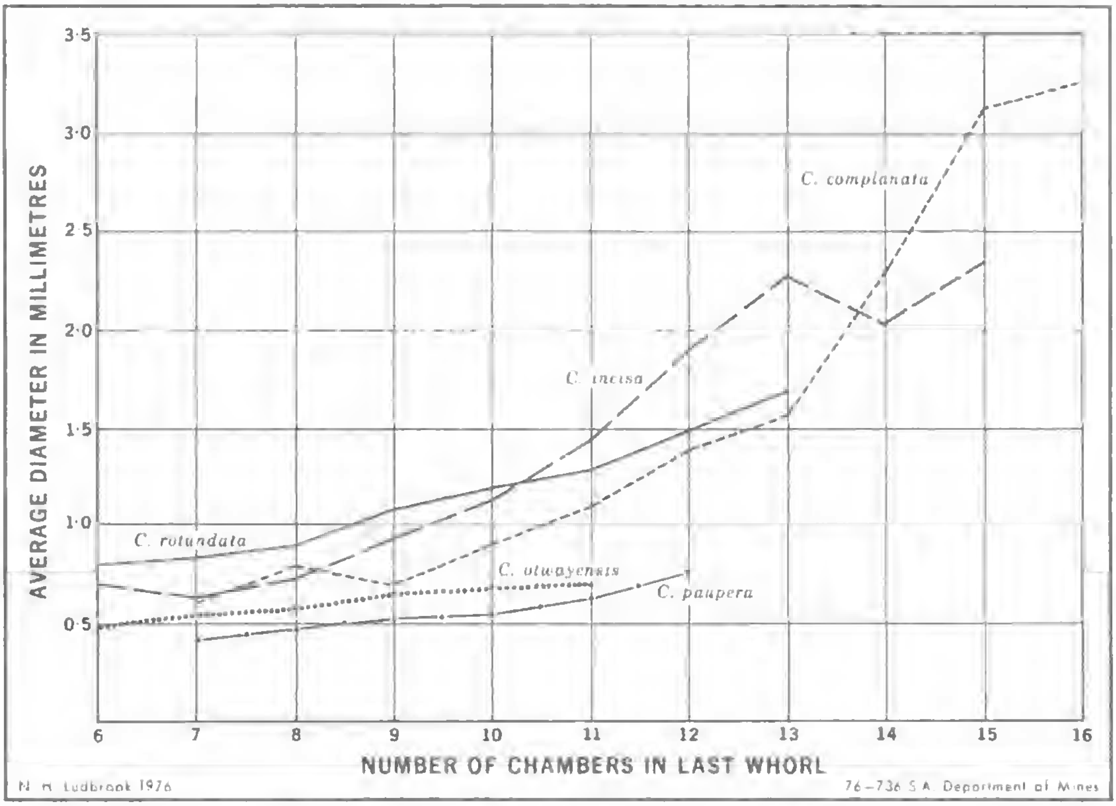


Figure 4. Relationship of number of chambers in last whorl and average diameter.

influence from the west was experienced during the Late Cretaceous, when the sea entered the western part of the Eucla Basin (Ludbrook 1958), the Duntroon Basin (Boeuf & Doust 1975) and the Otway Basin (Taylor 1964, 1971; Ludbrook 1971).

The Eucla Basin experienced an open sea environment during the Middle Eocene when carbonate sediments containing abundant planktonic foraminifers were deposited (Ludbrook 1963, 1969, McGowran & Lindsay 1969). Middle Eocene sediments in the Gambier Embayment of the Otway Basin, as exemplified by the Burrungule Member of the Tartwaup Formation, are paralic, highly carbonaceous clays and silts with sporadic planktonic foraminifers (Ludbrook 1971, p. 57) and also *Cyclammina otwayensis*. Open sea conditions reached the Port Campbell Embayment in the Late Eocene and the Torquay Basin shortly before the beginning of the Oligocene (Abele et al. 1976). Carbonate sedimentation began in the St Vincent Basin in the Late Eocene. The full extent of the easterly transgression did not affect most of the Murray Basin and the Bass and Gippsland Basins until the Oligocene to Early Miocene (see also Deighton *et al.* 1976, figs. 9–14).

Cyclammina flourished in the period when the Southeast Indian (Southern) Ocean was passing through the immature ocean phase; that is, in the period between the sporadic marine ingressions of the Late Cretaceous and the easterly spread of carbonate sedimentation extending into the Early Miocene.

The occurrence of *Cyclammina* spp. in southern Australia may be compared with that of *C. cancellata* described by Akers (1954) from the Louisiana Miocene where the species occurs in certain zones with planktonic foraminifers and abundantly in other zones to the exclusion of other foraminifers. Studying living *C. cancellata* from the Peru-Chile Trench, Theyer (1971a) observed that small and comparatively wide forms occur between 500 and 1000 m, with temperatures above 3° to 4 C. larger and proportionately narrow forms live at between 1000 and about 2500 m, below the permanent thermocline and in the oxygen minimum zone with oxygen content below 3 ml/l;

specimens living in deeper waters of more than 3000 m with temperatures below 2°C and oxygen values above 3 ml/l decrease slightly in diameter but widen considerably.

Gregarious in habit, is is found most abundantly as a "one-genus" assemblage (Akers 1954), or with almost all other genera excluded, in Palaeocene to Early Eocene paralic sediments of the Dilwyn Formation of the Port Campbell Embayment, Knight Group of the Gambier Embayment, and in the Late Eocene to Oligocene, Demon's Bluff Formation of the Torquay Basin. In the St. Vincent, Murray, Bass and Gippsland Basins it is associated with the early stages of the diachronous marine transgressions of the Late Eocene, Oligocene and Early Miocene. The sediments in which it is abundant and almost exclusive are usually highly carbonaceous; those in which it is associated with other benthonic foraminifers are frequently glauconitic. They are all assumed to have been deposited in shallow water, though palaeobathymetric studies have not been done in any detail.

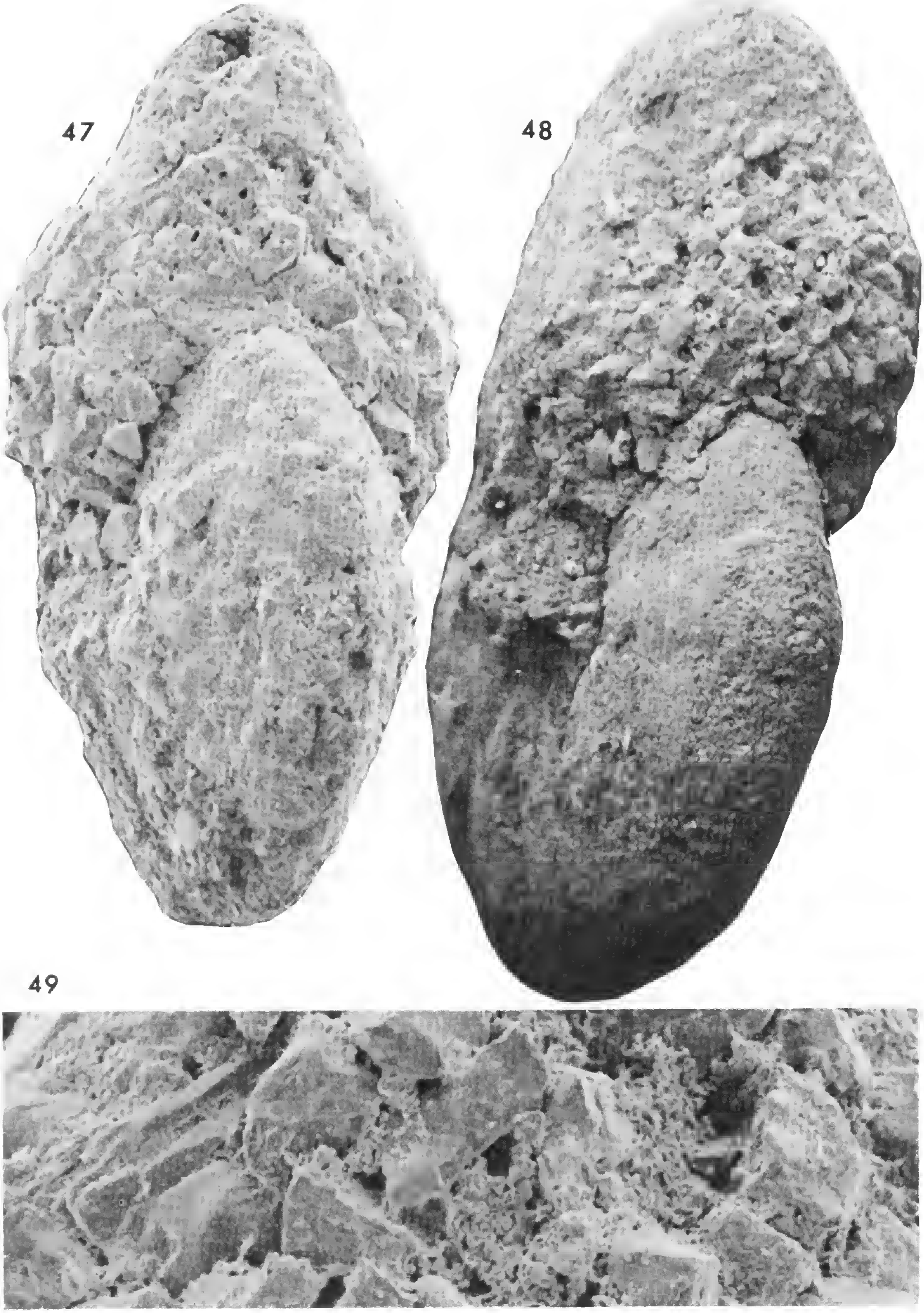
It was this apparently anomalous habitat for what has been accepted as a deep-water genus (Brady 1884; Akers 1954; Theyer 1971a, b; Boltovskoy & Wright 1976) that Taylor (1965) found difficult to accept. The living *Cyclammina cancellata* is widely distributed in oceanic waters off the continental shelves at depths between 114 and 5800 m, with a temperature range between 11.6° at depths 278 and 882 m and 1.2° at depth 5800 m in the North Pacific Ocean (Akers 1954). It does not occur in Antarctic waters (Theyer, 1971a). The only species living in Australian waters is *C. tasmanica* Parr, recovered from depths 155 and 122 m in bryozoal mud off Maria Island and at 128 m off northeastern Tasmania on the continental shelf (Parr 1950). These are shallow occurrences compared with depths of from 393 to 1718 m for the widely distributed *C. orbicularis* Brady and *C. pusilla* Brady dredged by B.A.N.Z. Antarctic Expedition (1929–1931) as well as by earlier "Challenger", Deutsche Sudpolar and "Scotia" Expeditions (Parr 1950, p. 273).

According to Theyer (1971b), *C. orbicularis* is the most characteristic index of lower bathyal to upper bathyal zones in the Pacific-Antarctic Basin. Abundant specimens begin to appear at approximately 1800 m and its lower depth limit normally lies between 3500 and 4000 m. *C. pusilla*, which is an index of abyssal depths, becomes significant at 3000–3500 m and disappears between 4500 and 5000 m. It undergoes size changes which probably parallel those of *C. cancellata* in the Peru-Chile Trench area.

While the bathymetry of the *Cyclammina*-bearing sediments, particularly in the Otway Basin, and the younger occurrences in the St. Vincent and Murray Basins remains to be studied, some broad interpretations of a limited area, based on microfaunas (Taylor 1971, figs 10–5 to 10–14) and computer-derived reconstructions of the continental margin based on quantitative seafloor spreading data (Deighton et al. 1976) have been made. It is, however, not possible to compare the patterns of bathymetric distribution of southern Australian *Cyclammina* species with that described by Robinson (1970) for Late Miocene to Holocene species in the Gulf of Mexico. Robinson's (Fig. 8) distribution patterns show that the bathymetric distribution of *Cyclammina* spp. decreased from a dominant abundance in the outer neritic–upper bathyal zone, between 137 and 384 m depth, during the Late Miocene–Early Pliocene to a normal distribution of rare but persistent examples from the lower bathyal zone (500 to 2000 m) in the Early Pleistocene.

The relevance of Robinson's studies is to dispel the conviction that the presence of *Cyclammina* is indicative of deepwater sedimentation and to emphasise that the use of generic distributions in palaeoecological interpretations must be made with caution, particularly if the abundance of the generic group differs markedly through time (Robinson 1970). Robinson also noted that, at the generic level, specimens associated with neritic assemblages are usually smaller, lighter in colour, coarser-grained, and with fewer chambers than those associated with bathyal assemblages. In the opinion of Murray (1973b) deepwater forms of *Cyclammina* are larger than the shallow water representatives. Boltovskoy & Wright (1976) show the depth distribution of *Cyclammina* as from the outer shelf to the abyssal zone. Quoting Sigal (1952), Pokorny (1958) and Bettenstaedt (1962), they state that genera such as *Haplophragmoides*, *Trochammina*, *Cyclammina* and *Bathysiphon* require little oxygen to survive.

The distribution and faunal associations of southern Australian species are shown in Table 3. Neritic assemblages in which *Cyclammina* is associated with planktonic and benthonic, other than agglutinated, forms occur principally in Late Eocene or younger sediments. The two species represented in these assemblages, *C.*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incisa and *C. rotundata*, are in general moderately large to large coarse-grained species, the greater proportion of which have relatively few chambers (see Table 3 and Fig. 4). The small fine-grained species *C. otwayensis* and *C. paupera* with fewer chambers and the large complex, fine-grained species *C. complanata* with more numerous chambers are restricted to Palaeocene to Middle Eocene paralic silts and sandy clays which, in the Wangerrip Group at least, are of shallow water origin (Baker 1950). Compared with the neritic assemblages the associated microfaunas are poor.

The largest examples of *C. complanata* were recovered from the Dartmoor Formation intersected in S.E.O.S. Beachport No. 1 Well and from outcrops on Glenelg River. Consistently large examples of *C. incisa* were collected from the Demon's Bluff Formation at Mogg's Creek. There are no data to suggest that these are deepwater representatives of those occurring at other localities.

Systematic descriptions

Order FORAMINIFERIDA Eichwald, 1830

Suborder TEXTULARIINA Delage & Hérourard, 1896

Superfamily LITUOLACEA de Blainville, 1825

Family LITUOLIDAE de Blainville, 1825

Subfamily HAPLOPHRAGMOIDINAE Mayne, 1952

Genus HAPLOPHRAGMOIDES Cushman, 1910

Haplophragmoides taylori n.sp.

PL. 2, FIGS 18-20

Haplophragmoides sp. B. Taylor, 1964: pl. 59, fig. 4; Taylor, 1965: 151, fig. 4 (3a, b).

Holotype: GSM 64829 (1); figured paratypes GSM 64829 (5).

Type locality: V.M.D. La Trobe No. 1 Well, Princetown, 38°41'49"S, 143°10'24"E, COLAC 1:250 000 geological map sheet, Core 53B at 292.61 m, Dilwyn Formation, Palaeocene to Early Eocene.

Material: 244 specimens of which 13 were measured as typical; the holotype and 6 paratypes from V.M.D. Wangoom No. 6, Core 12, 596–601 m, Dilwyn Formation, ?Early Eocene; 48 paratypes O.D.N.L. Mt Salt No. 1 509–590 m, Dartmoor Formation, Palaeocene to Early Eocene; 186 specimens ODNL Mt Salt No. 1, 1533–3061 m Sherbrook Group, Late Cretaceous.

Description: Test small, inflated, umbilicate, involute to slightly evolute, with 6 to 7 chambers in the last whorl, sutures straight, deeply incised, periphery lobulate, umbilicus deep and broad.

Wall finely agglutinated. Apertural face broad, high, aperture an interiomarginal slit without lip or with a slight lip.

Dimensions: Holotype diameter 0.35, thickness 0.20 mm; average of 13 uncollapsed specimens diameter 0.35; thickness 0.23 mm.

Remarks: Taylor (1964, p. 564; 1965, p. 151) described this distinctive small species of *Haplophragmoides*, which is common in Late Cretaceous sediments and occurs also in the Palaeocene of both the Port Campbell and Gambier Embayments of the Otway Basin. It is named in his honour.

Distribution: Otway Basin, Port Campbell and Gambier Embayments — Sherbrook Group, Belfast Mudstone and Paaratte Formations and their equivalents, Late Cretaceous (Turonian-Santonian (Taylor 1964)); Wangerrip Group, Dilwyn Formation, and Knight Group, Dartmoor Formation (Late Palaeocene to Early Eocene).

Subfamily CYCLAMMININAE Marie, 1941

Genus CYCLAMMINA Brady, 1879

Cyclammina complanata Chapman

PL. 2, FIGS 28-30; PL. 4, FIGS 41-44

Cyclammina complanata Chapman, 1904: 228, pl. 22, fig. 7.

Holotype: NMV Slide P26049 No. 6.

Type locality: Brown's Creek, between Rotten Point and mouth of Johanna River, 13.6 km NW of Cape Otway, 38°46'22"S, 143°23'14"E,

PLATE 6

Figs 47, 49. *Cyclammina incisa* (Stache), NZGS F100894, Demon's Bluff, Demon's Bluff Formation, Late Eocene, apertural view showing areal apertures; 1, X65; 3, enlargement of centre of apertural face, X240.

Fig. 48. *Cyclammina incisa* (Stache), NZGS F100937, Demon's Bluff, Demon's Bluff Formation, Late Eocene, apertural view showing areal apertures and coarse grains on apertural face, X34,

base of Johanna River Sands, ?Palaeocene to Early Eocene.

Material: 101 specimens of which 54 were measured and 8 sectioned. From outcrop—Glenelg River (7); from boreholes—O.D.N.L. Mt Salt No. 1, 585–954 m (84); S.E.O.S. Beachport No. 1, 408–603 m (9); B.P.N.L. Geltwood Beach No. 1, 579 m (1).

Description: Test large, composed mainly of quartz grains, planispiral, flattened, discoidal, partially evolute, with 2 whorls in the megaspheric form and 3 to 4 in the microspheric form; chambers 6 to 16, but 15 or 16 in the fully-grown adult, periphery narrowly rounded, very slightly lobulate, umbilicus well-defined, shallow, sutures incised, sinuate.

Wall agglutinated, thick, epidermis thin, smoothly finished, imperforate; hypodermis thick, alveolar, with a series of parallel alveolae distal to the septal wall but branching from the chamber lumen, all alveolae bifurcating just below the epidermis which they do not penetrate; the distal ends of the alveolae can be seen through the translucent epidermis as a fine punctate pattern or when they have been exposed by erosion of the epidermis.

Septal wall thick, arcuate, thickness as much as 6 times the interseptal width of the chamber lumen at its maximum width in equatorial section; in section each septal wall showing at least 7 more or less parallel alveolae extending from the supplementary apertures.

Chamber lumen much reduced, curved, both chamber lumina and alveolae lined with pseudochitin ("tectin", a combination of protein and carbohydrate (Hyman 1940)).

Apertural face high, more or less flattened laterally and rounded at the periphery, covered with fine quartz grains and with conspicuous supplementary areal apertures, each surrounded by a rim. Aperture an interiomarginal slit at the base of the apertural face.

Dimensions. Holotype diameter 2.0 mm. Of 54 specimens measured, diameter 0.45 to 3.75, average 1.08; thickness 0.18 to 1.12 mm, average 0.39 mm; average ratio diameter : thickness 2.8:1

Remarks: This is a rare species, occurring only from the Palaeocene to ?Early Eocene in the Otway Basin. It is a complex form of *Cyclammina* with greatly reduced chamber lumina and an extensive alveolar pattern similar to that of the *Cyclammina pilvoensis* Voloshinova & Budasheva group (see Banner 1970, pl. 3, figs 11, 12; pl. 13, figs 5–7) and *Cyclammina* aff. *tani* Ishizake (Banner 1970, pl. 13, figs 3, 4). From its external features it is obviously very close to *Cyclammina* sp. of Chang from the Shihliufeng sandy shale of the Liuchungchi oilfield, Taiwan (Chang 1956, pl. 1, figs 1–3).

Distribution: Otway Basin—Dartmoor Formation (Palaeocene to Early Eocene) and lower part of Johanna River Sands (?Late Palaeocene to Early Eocene).

Cyclammina incisa (Stache)

PL. 1, FIGS 5–8, 13; PL. 3, FIGS 31–35; ?FIG. 36; PL. 5, FIGS 45, 46; PL. 6, FIGS 47–49; PL. 7, FIGS 50–51; PL. 8, FIGS 52–53.

Haplophragmium incisum Stache, 1864: 165, pl. 21, fig. 1.

Haplopragmium maoricum Stache, 1864: 166, pl. 21, fig. 2.

Cyclammina paupera Chapman, 1904: 229 (in part). Crespin, 1950: 72, pl. 10, fig. 4 (not *C. paupera* Chapman, 1904, *sensu stricto*). Raggatt & Crespin, 1955: pl. 7, fig. 4 (not *C. paupera* Chapman, 1904, *sensu stricto*).

Cyclammina incisa (Stache) Chapman, 1926: 29, pl. 2, fig. 1. Chapman & Crespin, 1932: 14, pl. 15, fig. 6. Parr, 1938: 89, text fig. 1. Crespin, 1950: 72, pl. 10, fig. 3. Raggatt & Crespin, 1955: pl. 7, fig. 3. Hornibrook, 1961: 30; Hornibrook, 1971: 34, text fig. 9, pl. 6, figs. 88-91. Cockbain, 1974: 107, figs. 67A,B,C.

Haplophragmium canariense Chapman, 1926: 28, pl. 2, fig. 2 (not *Nonionina canariensis* d'Orbigny, 1839).

Cyclammina longicompressa Chapman & Crespin, 1930: 97, pl. 5, figs 3, 4.

Haplophragmoides cf. *incisa* (Stache) Taylor, 1965: 150, figs 2d, 3 (3a,b, 4a,b).

Haplophragmoides cf. *paupera* Taylor, 1965: 151, fig. 4 (2a, 2b) (not *Cyclammina paupera* Chapman, 1904).

"*Cyclammina*" cf. *incisa* (Stache) Lindsay & Bonnett, 1973: 33, pl. 1, fig. 4.

Cyclammina cf. *incisa* (Stache) Quilty, 1974, p. 33, pl. 1, figs 1–3 (in part).

Holotype: Slide 64, Naturhistorisches Museum, Vienna (Hornibrook 1971, p. 25).

Type locality: Grid reference N64/483465 (1948 ed.) Department of Lands and Survey, NZMS 1, Te Kopapa Point, Raglan Harbour (Whaingaroa), North Island, New Zealand, Whaingaroa Siltstone, Whaingaroan (Early Oligocene) (Hornibrook 1971, text fig. 1, pp. 9–10).

Material: 702 specimens, of which 390 were measured and 10 sectioned, from the following localities: Outcrops—topotypes, Raglan Harbour (18), Demon's Bluff (98), Mogg's Creek

(68), Castle Cove (76), Fossil Bluff (1), Abbotsford, New Zealand (2). Boreholes—O.D.N.L. Mt Salt No. 1, 719-1115 m (295); O.D.N.L. Mt Salt Structure Hole No. 1, 226–229 m (1); S.E.O.S. Beachport No. 1, 241–271 m (16); B.P.N.L. Geltwood Beach No. 1, 238–277 m (3); E. & W.S. Kingston No. 3, 65–69 m (2); E. & W.S. Coonalpyn No. 1, 69–70 m, 105–107 m (2); S.A.M.D. Waikerie No. 2, 149–152 m (20); S.A.M.D. Waikerie No. 28W, 146–148 m (1); Water Bore Plantagenet 5666, South Stirling 11.88–21.03 m (92), King's Park No. 2, 216–219 m (4); Parish of Bumberrah (Metung), 394.7 m (3).

Description: Adult test of moderate to large size, composed mainly of quartz grains, with usually 4 whorls in the microspheric form, 2 in the megaspheric form; 7 to 15 chambers in the last whorl, planispiral, biconvex, involute, more or less compressed at the periphery which is very slightly lobulate, depressed around the rather shallow umbilicus, sutures incised, straight to slightly sinuate.

Wall finely agglutinated, thick, epidermis thin, fine-grained, smoothly finished in fine sediment but varying according to the coarseness of the matrix, of uniform texture but for scattered large quartz grains, imperforate; hypodermis thick, coarse-grained, coarsely alveolar, not labyrinthic, the alveolae consisting of relatively simple tubes with a single conspicuous opening into the chamber lumen and bifurcating just below the epidermis, which they do not penetrate. The distal ends of the alveolae are frequently seen through the translucent epidermis of well-preserved specimens. Alveolae lined with organic material (pseudochitin or "tectin", a combination of protein and carbohydrate (Hyman 1940)), and the test is probably held together with organic cement.

Apertural face moderately rounded to roundly ogival, covered with coarse quartz grains between which fine supplementary areal apertures are sometimes visible. Aperture an interiomarginal narrow slit at the base of the apertural face.

Septal wall thick, about as wide as the interseptal width of the chamber lumina, occasionally perforated by the areal apertures.

Dimensions: Holotype, diameter 1.44 mm, thickness 0.90 mm (Hornibrook 1971). Of 390 specimens measured, diameter 0.28 to 3.0 mm, megaspheric 1.12 mm, average 1.15 mm; thickness 0.15 to 1.75 mm, average 0.54 mm; average ratio diameter : thickness 2.13:1. Diameter of early chambers 1.0 to 1.5 mm (microspheric). Number of whorls in early chambers (microspheric form) 3.

Remarks: C. incisa is a ubiquitous and long-ranging species with considerable variation in shape from fairly flat, mostly due to compression, with a diameter : thickness ratio of 4.5:1, to the robust form with a ratio of 1.6:1. Most of the topotypes from Raglan Harbour kindly lent by the New Zealand Geological Survey are rather flattened as compared with the holotype and matched topotype (Hornibrook 1971, p. 35, pl. 6, figs 88, 91). The specimen NZGS Reg. No. FP2078 sectioned by Hornibrook (1971, text fig. 9) appears to be a megaspheric form in which the chamber lumina have collapsed, as Hornibrook suggested. The same type of alveolar pattern is shown in the section of the relatively poorly preserved megaspheric specimen GSSA Ff612 (pl. 3, fig. 35) and in *C. praecancellata* Voloshinova as figured by Voloshinova & Budasheva 1961, pl. 15, figs 4, 5 and Muylaert 1966, pl. 42, figs 1-6. Well-preserved specimens (pl. 3, figs 31-33) clearly show an alveolar pattern and relative disposal of chamber lumina and septal wall of the same type as that of *C.* aff. *praecancellata* Voloshinova of Muylaert (1966, pl. 41, figs. 1–7; pl. 42, figs. 7–9; pl. 43, fig. 1). The section of *C. praecancellata* illustrated by Cicha & Zapletalova (1966, pl. 38, fig. 3c) shows a considerable reduction of the chamber lumina and more complex alveolar structure which is not readily comparable with that of *C. incisa.*

The record of the species in the Late Cretaceous Curdies Formation (Ludbrook 1971, fig. 3.3) is based on probable contamination of cuttings in Mt Salt No. 1 Well from the overlying Dartmoor Formation.

Distribution: Widespread in southern Australia and New Zealand from Late Palaeocene to Early Miocene.

Cyclammina otwayensis n.sp.

PL. 2, FIGS 23–25; PL. 4, FIGS 38–40

Haplophragmoides canariense Chapman, 1904: 228, pl. 22, fig. 2 (not *Nonionina canariensis* d'Orbigny, 1839).

Haplophragmoides complanata Taylor, 1965: 148, figs 2 (a–c), 3(1), (2) not *Cyclammina complanata* Chapman, 1904).

Holotype: GSSA Ff608, figured paratypes GSSA Ff609, Ff610.

Type locality: Glenelg River, Victoria, 2.4 km downstream from Killara Bridge, 14 km SW

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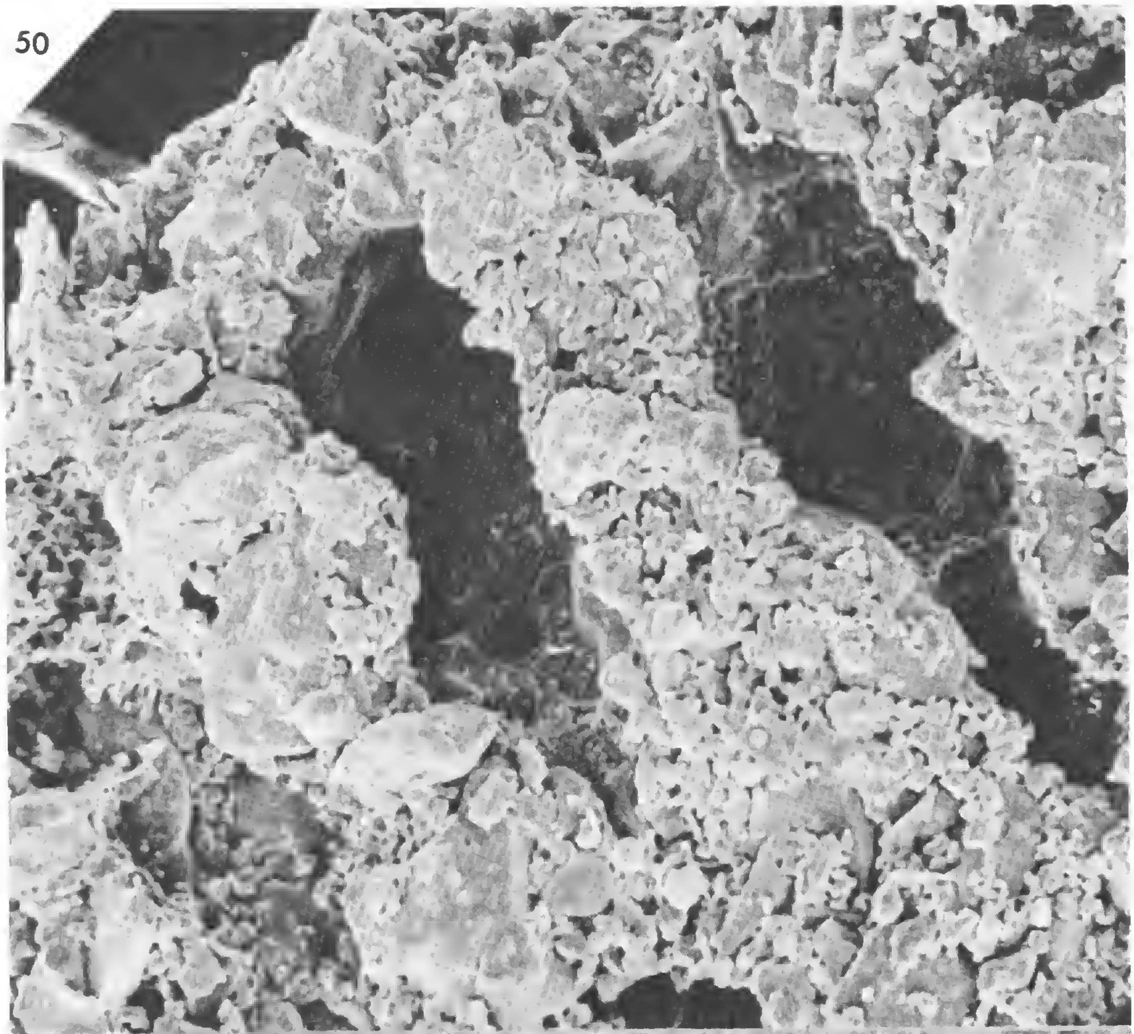

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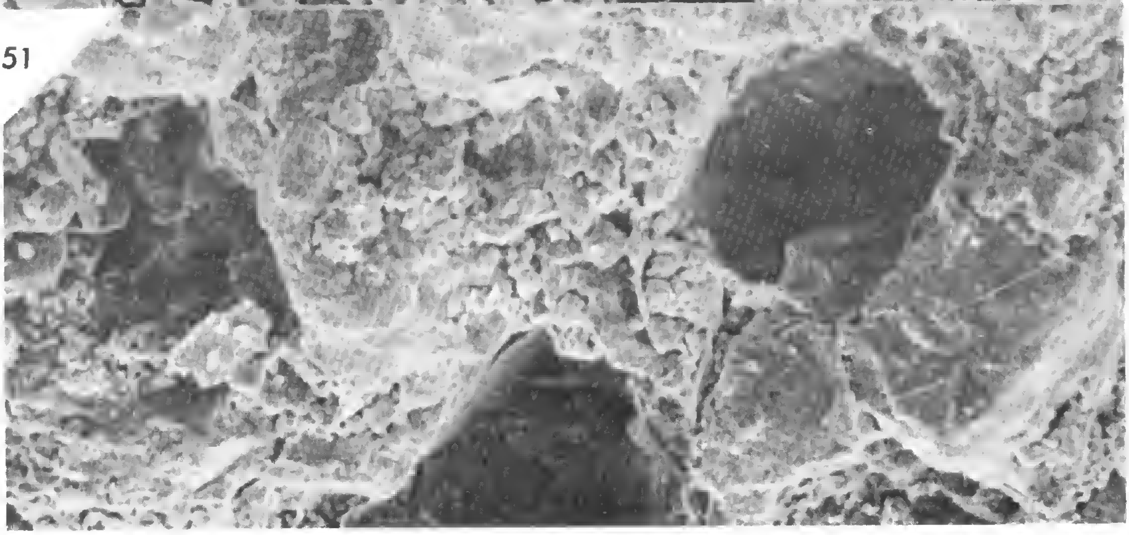


of Casterton, HAMILTON 1:250 000 geological map sheet, 37°39'56"S, 141°17'23"E, Gambier Embayment, Otway Basin, Dartmoor Formation, Palaeocene to Early Eocene.

Material: The holotype, figured paratypes and approximately 650 paratypes, of which 172 were measured and 4 sectioned, from: Outcrops—Brown's Creek (5), Glenelg River (43); Boreholes—V.M.D. La Trobe No. 1 at 298.7 m (500); S.A.M.D. C.G.9, County Grey, 28.96–29.26 m (63); O.D.N.L. Mt Salt No. 1, 585–960 (cavings 1039–1058 m) (23); S.E.O.S. Beachport No. 1, 311–546 m (25).

Description: Adult test small, moderately inflated, composed mainly of fine quartz grains with scattered medium grains which have a tendency to be arranged radially, planispiral, biconvex, involute, with 3 whorls in the microspheric form, 2½ in the megaspheric form, 7 to 11 chambers in the last whorl, but usually 8 to 9 in the adult form, sutures moderately well-defined, not incised, straight; periphery rounded, only slightly or not lobulate, umbilicus well-defined and relatively deep.

Wall rather loosely agglutinated, thin, with very little cementing material, epidermis relatively thick, smooth or roughly finished according to the coarseness of the grains of the enclosing sediment, imperforate; hypodermis thin, simply perforated by conspicuous alveolae having a large opening into the chamber lumen and branching distally from the chamber lumen to the epidermis which they do not penetrate but through which the distal ends can be seen in 2 or 3 radiating series per chamber. Septal wall moderately thin and occasionally punctured by the supplementary apertures. Apertural face a moderately high rounded arch covered with medium quartz grains between which very small supplementary areal apertures are occasionally visible.

Aperture a well-defined interiomarginal slit at the base of the apertural face, sometimes with a slight lip on the absutural side.

Chamber lumen widely open.

Dimensions: Holotype Ff608, diameter 0.75, thickness 0.41 mm; paratype Ff609, diameter 0.85, thickness 0.42 mm; paratype Ff610, diameter 0.80, thickness 0.40 mm. Of 172 specimens measured, diameter 0.35 to 0.90 mm, average 0.64 mm; thickness 0.12 to 0.42, average 0.30 mm; average ratio diameter : thickness 2:1.

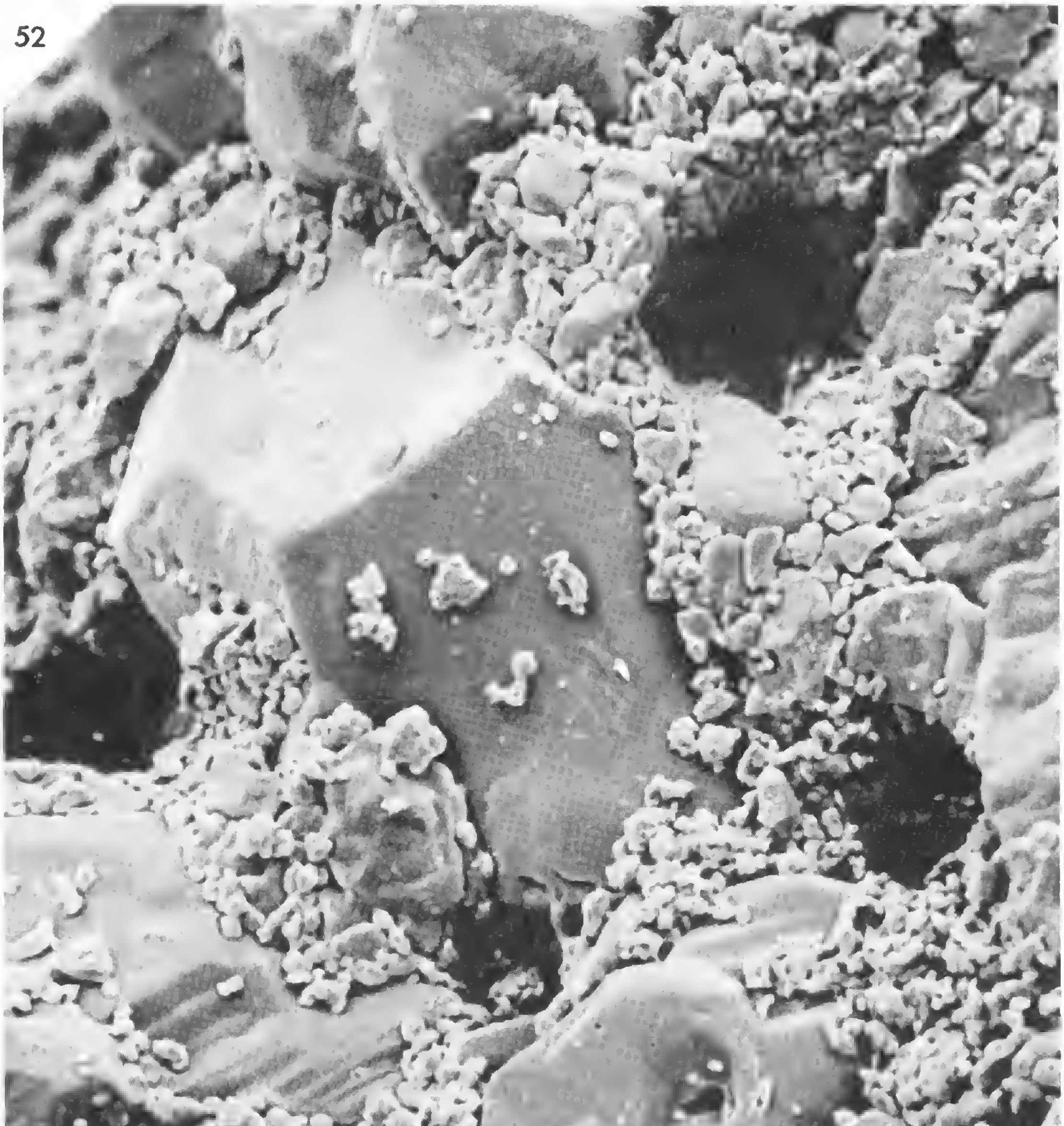
Remarks: Chapman (1904) identified this species as *Haplophragmium canariense* (d'Orbigny) (= *Nonionina canariensis* d'Orbigny, the type species of *Haplophragmoides* Cushman, 1910) and figured a specimen (pl. 22, fig. 2) which suggests the presence of alveolae below the epidermis. The figured specimen is, unfortunately, not the one now on Chapman's slide NMV P26049, but on square 33 of a slide GSM 64828 with mounted specimens from Chapman's material very kindly made available by D. J. Taylor, there are four specimens almost identical with the one figured by Chapman. These belong to *Cyclammina* as the open ends of alveolae can be seen on the inside of the chamber wall of one partially dissected specimen. Taylor (1965, p. 157) appears to have overlooked Chapman's separation of the species from *C. complanata* and interpreted the specimens on square 33 (GSM 64828) as *Haplophragmoides complanata*. He figured as "preservation stages" (p. 146, fig. 2a, b, c) three specimens from La Trobe No. 1 Bore at 298.7 m, which are here reinterpreted after examination of the specimens as an ontogenetic series of *C. otwayensis*. GSM 60464 (Fig. 2a) is a half section or "grind" of a pyrite-filled immature specimen; GSM 60465 (Fig. 2b) is a partly dissected specimen showing the open chamber lumina and relatively simple alveolar hypodermis; and GSM 60466 (Fig. 2c) is a half section or "grind" of a pyrite-filled specimen on the reverse side of which the alveolar openings beneath the epidermis are visible. GSM 60466 is similar to the specimen GSSA Ff609 figured on plate 2, figure 24.

The holotype is a rather coarse-grained specimen selected from a sample taken from

PLATE 7

Fig. 50. *Cyclammina incisa* (Stache), NZGS F100894, Demon's Bluff, Demon's Bluff Formation, Late Eocene, longitudinal view of alveolae from chamber lumen through hypodermis to epidermis, X550.

Fig. 51. *Cyclammina incisa* (Stache), NZGS F100937, Demon's Bluff, Demon's Bluff Formation, Late Eocene, distal ends of alveolae viewed from exterior through ruptured epidermis, X650.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the Dartmoor Formation on Glenelg River because of the accessibility of the outcropping material. The species is very abundant in the Palaeocene to Early Eocene of the Dilwyn Formation in La Trobe No. 1 Bore, and common in the type section (Bore CG9) of the Burrungule Member of the Tartwaup Formation.

The specific name is taken from the Otway Basin to which it is restricted on present knowledge.

Distribution: Otway Basin–Dilwyn and Dartmoor Formations (Palaeocene to Early Eocene) and lower part of Johanna River Sands (?Palaeocene to Early Eocene); Burrungule Member of Tartwaup Formation (Middle Eocene).

Cyclammina paupera Chapman

PL. 2, FIGS 21, 22, 26, 27; PL. 4, FIG. 37

Cyclammina paupera Chapman, 1904: 229, pl. 22, fig. 6.

Haplophragmoides paupera (Chapman) Taylor, 1965: 151, fig. 4 (1a,b) (not *Cyclammina paupera* Crespin, 1950:72, pl. 10, fig. 4).

Holotype: NMV Slide P26049 No. 5.

Type locality: Brown's Creek, between Rotten Point and mouth of Johanna River, 13.6 km NW of Cape Otway, 38°46′22″S, 143°23′14″E, base of Johanna River Sands, ?Palaeocene to Early Eocene.

Material: 86 specimens of which 52 were measured. From outcrops — Brown's Creek (3), Glenelg River (7); from boreholes — V.M.D. La Trobe No. 1 293–299 m (63), V.M.D. Wangoom No. 6, 596–600 m (9), O.D.N.L. Mt Salt No. 1, 902–957 m (63).

Description: Adult test small, planispiral, flatly biconvex, involute or slightly evolute, composed of fine quartz grains, compressed towards the periphery which is acute, rounded or slightly lobulate; umbilicus well-defined, deep. Six to twelve chambers in the last whorl, but usually 8 to 10 in the adult form; sutures incised, straight or slightly arcuate.

Wall finely agglutinated, thin, epidermis very thin, with fine alveolae visible through the translucent epidermis when the specimen is wet, otherwise apparently absent or poorly developed. Septal wall thin. Chamber lumen widely open, subtrapezoidal in section, each chamber tends to be set almost above the corresponding chamber of the previous whorl, so that both chambers and septa appear in equatorial section as unbroken radii (pl. 4, fig. 37).

Apertural face high, narrow, subtriangular, covered with fine quartz grains; aperture a very narrow interiomarginal slit at the base of the apertural face, without lip.

Dimensions: Holotype diameter 1.08 mm. Of 52 specimens measured diameter 0.37 to 1.08, average 0.52 mm; thickness 0.12 to 0.25, average 0.20; average ratio diameter : thickness 2.6:1.

Remarks: In texture of the epidermis, in size and general shape, *C. paupera* may be compared with *C. grangei* Finlay, which has a similar stratigraphical range of Late Palaeocene to Middle Eocene (Hornibrook 1968, p. 48). *C. paupera* is flatter and less elevated around the umbilicus, and in *C. grangei* the alveolar pattern as indicated by the distal ends of the alveolae visible through the siliceous wall is much coarser and more strongly developed.

The specimen (CPC 645) figured by Crespin (1950, pl. 10, fig. 4) is a rather deflated example of *C. incisa*, not unlike topotypes from Raglan Harbour. The specimen figured as *Haplophragmoides* sp. A (Taylor, 1964, p. 563, pl. 9, fig. 3) and placed in synonymy with *Cyclammina paupera* (Taylor, 1965, p. 151) appears to be a *Haplophragmoides* and not *C. paupera*, the occurrence of which in the Late Cretaceous has not been confirmed.

Distribution: Otway Basin–Dilwyn and Dartmoor Formations (Palaeocene to Early Eocene) and lower part of Johanna River Sands (?Palaeocene to Early Eocene).

Cyclammina rotundata Chapman & Crespin

PL. 1, FIGS 9–12, 14–17; ?PL. 3, FIG. 36

Haplophragmium latidorsatum Chapman, 1904: 227, pl. 22, fig. 1 (not *Nonionina latidorsata* Bornemann).

Cyclammina rotundata Chapman & Crespin, 1930: 96, pl. 5, figs 1, 2. Crespin, 1950: 72, pl. 10, figs 5a, 5b. Raggatt & Crespin, 1955: pl. 7, figs 5a, 5b.

PLATE 8

Fig. 52. *Cyclammina incisa* (Stache), NZGS F100937, Demon's Bluff, Demon's Bluff Formation, Late Eocene, alveolae viewed from chamber lumen, X650.

Fig. 53. *Cyclammina incisa* (Stache), NZGS F100937, Demon's Bluff, Demon's Bluff Formation, Late Eocene, epidermis, X2500.

Haplophragmoides rotundata (Chapman & Crespin) Taylor, 1965: 153, fig. 4 (4a, b).

Cyclammina cf. *incisa* (Stache) Quilty, 1974: 33, pl. 1, figs 1–3 (in part at least).

Holotype: CPC 14.

Type locality: No. 1 Bore Parish of Bumberrah, Metung, Victoria, BAIRNSDALE 1:250 000 geological map sheet, 37°53′34″S, 147°50′14″E, at 394.7 m depth, Gippsland Basin, Lakes Entrance Formation, Oligocene.

Material: The holotype and 107 specimens of which 93 were measured and 5 sectioned. From outcrops—Demon's Bluff (4), Castle Cove (5). From boreholes—O.D.N.L. Mt Salt No. 1 908–1015 m (22), S.E.O.S. Beachport No. 1 238–271 m (41); New Morphett Street and Victoria Bridges, Adelaide, Bore 11 25–25.6 m (2), Bore 12 20.1–20.4 m (1), Bore 14 16.7–17.0 m (2); "Carclew" Bore 2 19.8–19.9 m (1), Observation Bore F, Port Gawler, 253–254.5 m (2), Waikerie Bore 28W, 146 m (15), Plantagenet Location 5666, South Stirling, 11.88–21.03 m (33).

Description: Adult test of moderate to large size, inflated, planispiral, biconvex, involute, composed mainly of coarse quartz grains, with 4 whorls in the microspheric form, 6 to 12, rarely 13, chambers in the last whorl, periphery rounded, umbilicus scarcely or not depressed, sutures poorly defined, straight.

Wall agglutinated, thick, epidermis thin and usually coarsely finished with numerous agglutinated coarse grains, imperforate; hypodermis thick, coarse-grained, alveolar, with a pattern of fine roughly parallel alveolae with only a slight tendency to bifurcate distally beneath the epidermis. The distal ends of the alveolae are not usually visible through the epidermis. Septal wall thick, chamber lumen much reduced.

Apertural face a low arch covered with coarse quartz grains between which small supplementary areal apertures are frequently visible. Aperture a slit at the base of the apertural face, short and well open in immature specimens.

Dimensions: Holotype diameter 1.4, thickness 0.82 mm. Of 93 specimens measured, diameter 0.5 to 2.12 mm, average 1.13 mm; thickness 0.30 to 1.50 mm, average 0.73 mm. Average ratio diameter : thickness 1.55:1.0.

Remarks: The specimen figures as *Haplophragmoides* sp. C. (Taylor 1964, p. 564, pl. 79, fig. 5) and placed in synonymy with *Cyclammina rotundata* (Taylor 1965, p. 153) appears to be a *Haplophragmoides* and not *C. rotundata*, the occurrence of which in the Late Cretaceous has not been confirmed. The record of the species in the Late Cretaceous Curdies Formation (Ludbrook 1971, fig. 3.3) is based on probable contamination of cuttings in Mt Salt No. 1 Well from the overlying Dartmoor Formation.

Distribution: Widespread in Australia and New Zealand, associated with *C. incisa*, from Late Palaeocene to Oligocene and possibly Early Miocene.

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A NEW SPECIES OF DIPORIPHORA FROM SOUTH AUSTRALIA AND GEOGRAPHIC VARIATION IN D. WINNECKEI LUCAS & FROST (LACERTILIA: AGAMIDAE)

BY TERRY F. HOUSTON

Summary

A new species of dragon lizard, Diporiphora linga, is described from western South Australia. It is closely related to D. winnecki and, in order to facilitate comparison, the geographic variation of winnecki is briefly reviewed with the recognition of two distinct races. Notes on the habitats of the two species are included.